

Spatio-temporal evolution of urban innovation structure based on zip code geodatabase: An empirical study from Shanghai and Beijing

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Abstract: In today's world, the innovation of science and technology has become the key support for improving comprehensive national strength and changing the mode of social production and lifestyle. The country that possesses world-class scientific and technological innovation cities maximizes the attraction of global innovation factors and wins a strategic initiative in international competition. Based on the urban zip code geodatabase, an evaluation system of urban innovation with the perspective of innovation outputs, and the spatial evolutionary mode, concerning the structure of innovation space of Shanghai and Beijing from 1991 to 2014, was developed. The results of the research indicated that the zip code geodatabase provided a new perspective for studying the evolving spatial structure of urban innovation. The resulting evaluation of the spatial structure of urban innovation using the urban zip code geodatabase established by connecting random edge points, was relatively effective. The study illustrates the value of this methodology. During the study period, the spatial structure of innovation of Shanghai and Beijing demonstrated many common features: with the increase in urban space units participating in innovation year by year, the overall gap of regional innovation outputs has narrowed, and the trend towards spatial agglomeration has strengthened. The evolving spatial structure of innovation of Shanghai and Beijing demonstrated differences between the common features during the 25 years as well: in the trend towards the suburbanization of innovation resources, the spatial structure of innovation of Shanghai evolved from a single-core to a multi-core structure. A radiation effect related to traffic arteries as spatial diffusion corridors was prominent. Accordingly, a spatial correlation effect of its innovation outputs also indicated a hollowness in the city center; the spatial structure of innovation of Beijing had a single-core oriented structure all the way. Together with the tendency for innovation resources to be agglomerated in the city center, the spatial correlation effect of innovation outputs reflected the characteristics of the evolutionary feature where "rural area encircles cities". The innovation spatial structure of Shanghai and Beijing have intrinsic consistency with the spatial structure of their respective regions (Yangtze River Delta urban agglomeration and Beijing-Tianjin-Hebei metropolitan region), which suggested

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that the principle of proportional and disproportional distribution of a city-scale pattern of technological and innovational activities is closely related to its regional innovation pattern.

Keywords: innovation outputs; zip code; spatio-temporal evolution; agglomeration and dispersion

1 Introduction

Nowadays, technological innovation has become the main support of comprehensive national strength and a powerful driver of production mode and lifestyle transition. Any country that possesses a world-class innovation city will be most capable of attracting global innovation elements to obtain a strategic initiative in international competition (Du, 2015). Since the 21st century, a new wave of scientific and technological innovation has been in the ascendant and the world political and economic landscapes have been changing rapidly: the global high-end production factors and innovation elements have been accelerating the transfer to the Asia-Pacific region, and the global pattern of scientific and technological innovation is showing a shifting trend from the West to the East. Compared to other countries in the Asia-Pacific region, and as the largest country in Asia and the world's second largest economy, China possesses more resources and a wider market to become the global technology innovation center (Du, 2014; Du *et al.*, 2015). According to the Innovation Cities™ Index (2009-2014), Shanghai has risen from being a Hub City in 2009 to being a Nexus City in 2014; Beijing has also risen from being a Node City in 2009 to being a Hub City in 2014. With the increase in innovation strength, Shanghai, Beijing and other Chinese mainland cities are increasingly playing a more important role in the global innovation city network.

Since Schumpeter first introduced innovation theory from the perspective of economics, the discussion on innovation has been continuously debated. Due to the increasingly obvious spatial trends of Humanities and Social Science and the increasingly mature spatial econometric analysis methods based on GIS, spatial research on innovation has become a key focus of many scholars, and includes the following topics: (1) Spatial distribution of innovation activities. The research scale ranges from county, city, provincial to the national level and the research methods are focused on *Moran's I Index*, *Location Gini Coefficient*, *Lorenz Curve*, *Variation Coefficient* and other statistical methods. All the results revealed that innovation activities were highly concentrated and spatially imbalanced, revealing a scale-free property in the spatial distribution of innovation activities (Lim, 2003; Zhang *et al.*, 2007; Liu, 2010; Wang *et al.*, 2014; Jiang, 2014). (2) Spatial spillover effects of regional innovation. It was discovered that there was a significant spatial correlation in terms of innovation among regions (Moreno *et al.*, 2005; Su, 2006; Zhang, 2013; Guastella *et al.*, 2015). Unlike the scale-free dependency of spatial distribution of innovation activities, there was a certain degree of spatial limitations in knowledge spillovers (Lei Liang, 2015). (3) Influencing mechanism of the spatial distribution difference of innovation activities. Research in this area mainly established a regression model taking the innovation outputs or innovation efficiency as the dependent variable to reveal the factors influencing the spatial differences of innovation, which included innovation policy, foreign direct investment (FDI), enterprise scale, the industrial clusters and innovation environment, etc. (Geroski, 1990; Yu *et al.*, 2007; Fan *et al.*, 2013; Li *et al.*, 2013; Felsenstein, 2015). (4) Spatial evaluation of innovation strength and efficiency. Studies on the evaluation of regional innovation strength are mainly

carried out by constructing a comprehensive evaluation and analysis model based on a series of evaluation index systems to explore the spatial differentiation between cities, regions or provinces (Tao, 2013; Fang *et al.*, 2014; Makkonen *et al.*, 2014). Research on regional innovation efficiency was usually conducted from the input-output view to compare the efficiency of innovation activities at different spatial scales (Wang *et al.*, 2011; Chen *et al.*, 2012; Fan *et al.*, 2013; Cheng *et al.*, 2014). (5) Collaborative research on innovation and regional development. The driving effect of innovation on economic development has caught a large number of scholars' attention since the 1990s. On the basis of a comprehensive evaluation of regional innovation strength and economic development level, a series of relational models were used to study the response and matching degree in space between regional innovation and its socioeconomic development (Wang, 1999; Cheng *et al.*, 2011; Niu *et al.*, 2012). (6) Research on innovation links and innovation networks. The research scales concerning this topic were relatively macro, mainly including a country or a city on the global scale and a provincial or a prefecture-level city on the national scale. The research methods and perspectives were mainly on three aspects. The first was to study the spatial location and structure of the global R&D network by taking the global layout of research institutes of the Multi-National Corporation as an example from the perspective of enterprise spatial organization (Zhu *et al.*, 2005; Zhang, 2015). The second was to measure the regional innovation contact intensity and pattern according to the innovation space gravity model based on the evaluation of regional innovation strength (Lyu *et al.*, 2015). The third was to study the structure and spatial complexity of the regional innovation network based on the social network analysis model from the perspective of regional innovation cooperation (Lyu *et al.*, 2014; Li *et al.*, 2015; Li *et al.*, 2015; Berger *et al.*, 2015).

In current innovation spatial research, it is not hard to find that there are three aspects to be carefully discussed. Firstly, medium and macro scale favoritism makes current innovation spatial research unable to sum up the evolution model of innovation space, so the optimization strategies of regional innovation spatial structure are often difficult to implement because of the transboundary nature of administrative jurisdiction. Secondly, when taking the administrative boundary as the research unit, there is no way to avoid the merging problems of statistical data resulting from administrative division reform, and when we look at this issue at the city level, we find that it becomes more serious, because adjustments of administrative divisions within the city are clearly more frequent. Thirdly, difficulties in obtaining statistical data on innovation for counties, streets and towns create obstacles for expanding spatial innovation research to inner city areas faced with great obstacles, resulting in city-scale spatial innovation research having the following features: (1) taking the innovation subjects as research objects and studying their innovation ability, efficiency and the relations among them, such as the enterprises, colleges and universities and other scientific research institutions (Hu *et al.*, 2014); (2) choosing a hi-tech park or a creative industrial park as the example and studying the innovation spillover, innovation efficiency, spatial enterprise organization and its impact on regional economic development of the park (Zhu *et al.*, 2010; Zhou *et al.*, 2011); (3) taking knowledge production as the perspective and studying the city's innovative functions and urban innovation system (Lyu *et al.*, 2014); (4) taking the urban internal administrative divisions as the space carrier and studying the impact of innovation on economic development (Yang, 2007; Liu, 2010). However, we cannot extri-

cate ourselves from the difficult position of overgeneralization whether taking the innovation subjects or hi-tech parks as the research objects. Even from the perspective of the county, the study of urban innovation still appears to be more macro, thus we cannot interpret the evolution of urban innovation spatial structure.

In general, in order to explore the evolution of a city's innovation spatial structure systematically, we should overcome the inertia associated with the boundaries of administrative division, so as not to be affected by the discontinuity of statistical data, and we have to move on from the tradition of studying innovation subjects or favoring hi-tech parks, thus having a comprehensive understanding of the spatial agglomeration and diffusion processes of urban innovation. In this context, the zip code geodatabase provides a new perspective for the study of the evolution of urban innovation spatial structure. First, the zip code geodatabase has not changed with the step reforms of administrative divisions, so the spatial data on innovation based on the zip code has a good temporal extension. Second, with a perfect spatial coverage, the zip code geodatabase can reveal the evolving innovation structure of the whole city from a more microcosmic perspective. Third, there is a good correlation between the zip code and the innovation data, especially when using papers and patents as the outputs of innovation. Therefore, in order to provide a new perspective to explore the mechanism underlying the spatial structure of urban innovation and to provide a reference for the implementation of urban innovation space optimization policy, this paper constructs an evaluation index system of urban innovation outputs based on the urban zip code from the perspective of innovation outputs to research the model of evolving urban innovation structure in Shanghai and Beijing.

To this end, the remainder of this paper is organized as follows. Section 2 describes the data and methodology. In Section 3, the spatial pattern and the model of evolving urban innovation structure in Shanghai and Beijing are shown. Section 4 reveals the spatial correlation and agglomeration evolution of urban innovation structure in Shanghai and Beijing. Section 5 ends with a main conclusion and lists future tasks.

2 Research methods

2.1 Zip code geodatabase

Based on the zip code data in China Post Media Data Center, this paper takes the unit addresses of each zip code as the modified basis to construct the zip code geodatabase of Shanghai and Beijing (Shanghai city has 249 pieces of zip code, Beijing has 239)¹. And we use the Tyson Polygon Method to construct the spatial point database of zip code (Figure 1), to realize an effective, comprehensive and continuous evaluation of city innovation from the angle of internal urban space.

¹The detailed method is to determine a zip code area by connecting edge points. First, randomly selecting 10% unit addresses of each zip code, then marking them on Baidu Map. Secondly, connecting the points to determine the zip code area. Thirdly, randomly selecting 5% from the remaining units for checking, if they are all in this region, the range will be regarded as the area that is represented by the zip code; if some codes are out of the edge line, then repeating the connection and correction steps until they are all in the range. Finally, based on the ArcGIS spatial analysis platform, taking the geometric center points of each zip code area as the actual distribution points of the zip code so as to construct the encoding spatial point geodatabase of zip code.

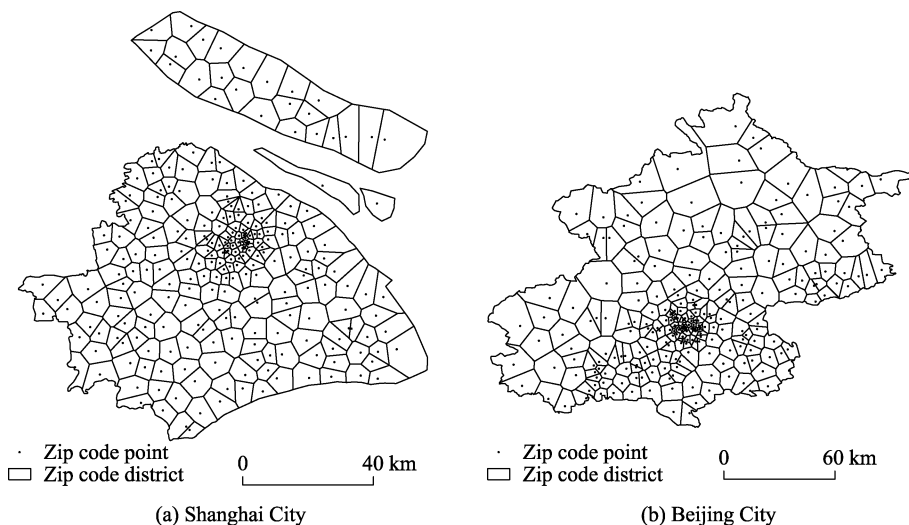


Figure 1 Zip code geodatabase of Shanghai and Beijing

2.2 Evaluation index system and the city profile

Scholars had different opinions on the evaluation index system of urban innovation. Limited from obtaining the innovation statistical data, most scholars used the patent data (application or authorization) to measure city or regional innovation capability from the perspective of innovation outputs (Zhang *et al.*, 2007; Liu, 2010; Jiang, 2014; Wang *et al.*, 2014). But there remain a few scholars that tried to build a comprehensive evaluation system of urban innovation including innovation input, innovation outputs, innovation environment, and other aspects through field survey, telephone consultation and other means to obtain a detailed account of the innovative data (Fan *et al.*, 2013; Tao *et al.*, 2013; Cheng *et al.*, 2014; Fang *et al.*, 2014). Compared with those individual scholars lacking funding and data, the innovation strength of evaluation systems developed by think tanks or decision-making consultancies with strong financial support was much greater, such as 2thinknow, the Australian think tank constructed an assessment system for global innovation city made up of 162 indicators including cultural assets, human capital, networked market and authorization on patents (Fang *et al.*, 2014).

In the process of building the evaluation system of urban innovation, this paper found out that only the indexes of papers and patents of the innovation outputs can be used to identify the zip code. Despite their small proportion in the evaluation index of urban innovation strength, they have been used by many scholars to evaluate the innovative ability of the city or region, especially since patent remains the most appropriate and typical index to describe knowledge innovation (Cheng *et al.*, 2014). As for papers, scholars used “Number of Papers Published” consistently as an evaluation indicator (Hu *et al.*, 2014). However, some gaps exist between the application and granting of patents. We should also consider that patent licensing is largely influenced by some artificial factors such as government patent agency, whether the patent is approved or not, the application process of a patent reflects the investment in the early stage. Meanwhile, the number of patent applications can also reflect the innovation activity of a region. Therefore, based on the zip code geodatabase, this paper

chose the two indicators of “Number of Papers Issued on Core Magazines” and “Invention Patent Applications” to construct the evaluation system of urban innovation from the perspective of innovation outputs. The core magazines not only include the Source Journals of Chinese Social Sciences Citation Index (CSSCI) and Chinese Science Citation Database (CSCD), but also include the Source Journals of Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). The applications of invention patent include Chinese invention patent applications based on Wanfang Data Knowledge Service Platform and the international patent applications represented by PCT of the World Intellectual Property Organization (WIPO).

From 1991 to 2014, with the increasing number of urban zip code districts participating in innovation, the innovation outputs of Shanghai and Beijing also shows a rising trend. The total number of the papers issued on CSSCI and CSCD in Shanghai is 1,017,772; the average annual growth rate is 43.87%. The papers published on SCI and SSCI numbered 110,991, with the average annual growth rate of 341.40%. The number of Chinese invention patent applications is 235,721, and the international is 12,986, with an average annual growth rate of 1965.48%. Over the same period, the number of Chinese core papers in Beijing was 1,625,723, and the number of foreign core papers was 270,875. Both are far more than Shanghai, but the average annual growth rate was lower than Shanghai, respectively, 41.54% and 299%. In addition, during 1990–2014, the numbers of Chinese invention patent applications in Beijing was 292,167, and international was 16,505, both being higher than Shanghai. While the average annual growth rate of international invention patent applications is also lower than that of Shanghai, the rate of Chinese invention patent applications was higher than Shanghai (303.69%) by nearly 140% (Table 1).

Table 1 Overview of papers and patents for invention of Shanghai and Beijing

City	Indicators	1991–1995	1996–2000	2001–2005	2006–2010	2011–2014	Total
Shanghai	Number of zip code areas participating in innovation	170	228	246	249	248	/
	Papers issued on CSSCI and CSCD	26381	83892	243529	359804	304166	1017772
	Papers published on SCI and SSCI	527	3628	16695	46434	43707	110991
	Chinese invention patent applications	1539	6874	28324	85273	113711	235721
	International patent applications	14	232	2033	4089	6618	12986
Beijing	Number of zip code areas participating in innovation	144	179	212	231	236	/
	Papers issued on CSSCI and CSCD	42238	118544	343556	658073	463312	1625723
	Papers published on SCI and SSCI	2034	8758	30200	81888	147995	270875
	Chinese invention patent applications	5521	8496	33985	95389	148776	292167
	International patent applications	65	397	1675	5852	8516	16505

2.3 Catastrophe progression method

Using cusp catastrophe model to solve the urban innovation comprehensive index:

$$f(x) = x^4 + ax^2 + bx \quad (1)$$

where $f(x)$ is the potential function of state variables x ; a and b indicate the control variable of the state variable x .

The normalized formula is $x_a = \sqrt{a}$, $x_b = \sqrt[3]{b}$

Because of the obvious complementarity between selected indicators in this study, we use an average value method to determine the appraised value of each index and the comprehensive evaluation value.

2.4 Spatial autocorrelation analysis

Using global Moran's I statistics to measure spatial correlated degree of the city's zip code districts and their neighborhood on innovation outputs, the statistics can be expressed as:

$$\text{Moran's } I = \frac{\sum_{i=1}^n \sum_{j \neq i}^n W_{ij} Z_i Z_j}{\sigma^2 \sum_{i=1}^n \sum_{j \neq i}^n W_{ij}}, \left(Z_i = \frac{X_i - \bar{X}}{\sigma}, \bar{X} = \frac{1}{n} \sum_{i=1}^n X_i, \sigma = \frac{1}{n} \sum_{i=1}^n (X_i - \bar{X})^2 \right) \quad (3)$$

where, n is the number of space units; W_{ij} is the spatial weight matrix; Z_i is standardization transformation of X_i (the attribute value of space unit i). The value of Moran's I ranges from -1 to 1 . Tending to 1 indicates the absolute positive spatial correlation; tending to 0 means a random distribution; tending to -1 indicates the absolute negative correlation.

Local indicators of spatial association (LISA) assumes that being adjacent to each other for every space unit helps identify the hot spots of innovation input and outputs. The statistics can be expressed as:

$$\text{Local Moran's } I = Z_i \sum_{j=1}^n W_{ij} Z_j \quad (4)$$

The positive values indicate the same type of elements is adjacent; the negative value indicates that different types of elements are adjacent, and the greater the absolute value of the numerical value is, the greater the spatial proximity is.

3 Spatial evolution pattern of urban innovation outputs

3.1 Statistical commonality of Shanghai and Beijing

To describe the statistical distribution features of the urban innovation outputs clearly, this paper introduces the *Range method* (R), the *Standard Deviation* ($S-D$), the *Variation Coefficient* ($V-C$) and the *Gini Coefficient* ($G-C$) based on *Global Moran's I Index* ($M-I$) to explore the distribution of urban innovation outputs. No more calculation methods are listed here due to the universality (Table 2).

During the last 25 years, the R and $S-D$ of innovation outputs both in Shanghai and Beijing have expanded year by year. Respectively, the range of which have risen from 2.035 and 2.492 in 1991 to 4.223 and 5.049 in 2014; the standard deviation of which have risen from

0.536 and 0.665 in 1991 to 0.644 and 0.936 in 2014. These values show that with the rising strength of urban innovation and the increasing number of spatial units that participate in urban innovation, the statistical characteristics of urban innovation outputs present a severe shock trend. Although the weak will not be weaker, the rich gets richer.

During the last 25 years, the *V-C* and *G-C* of innovation outputs both in Shanghai and Beijing showed a downward trend, in which the *V-C* decreases from 0.900 and 1.043 in 1991 to 0.353 and 0.601 in 2014 respectively; the *G-C* decreases from 0.502 and 0.570 to 0.194 and 0.334, which shows that in the expanding process of innovation outputs in Shanghai and Beijing, the statistical distribution of innovation outputs presents a trend from a low level of agglomeration to optimized and balanced development.

From 1991 to 2014, the *M-I* of Shanghai and Beijing are higher than 0, showing a general ascending trend, respectively rising from 0.383 and 0.519 in 1991 to 0.565 and 0.727 in 2014. In both cities, innovation outputs had significant positive correlations in space, and presented a strongly concentrated spatial pattern. It is worth mentioning that, although the two cities showed a continuous increase in the spatial polarization trend, the degree of polarization in Beijing is more significant. Besides, the index values are higher than Shanghai in all five periods. Compared with Beijing, Shanghai's decentralized agglomeration trend of innovation outputs spatial patterns has been highlighted.

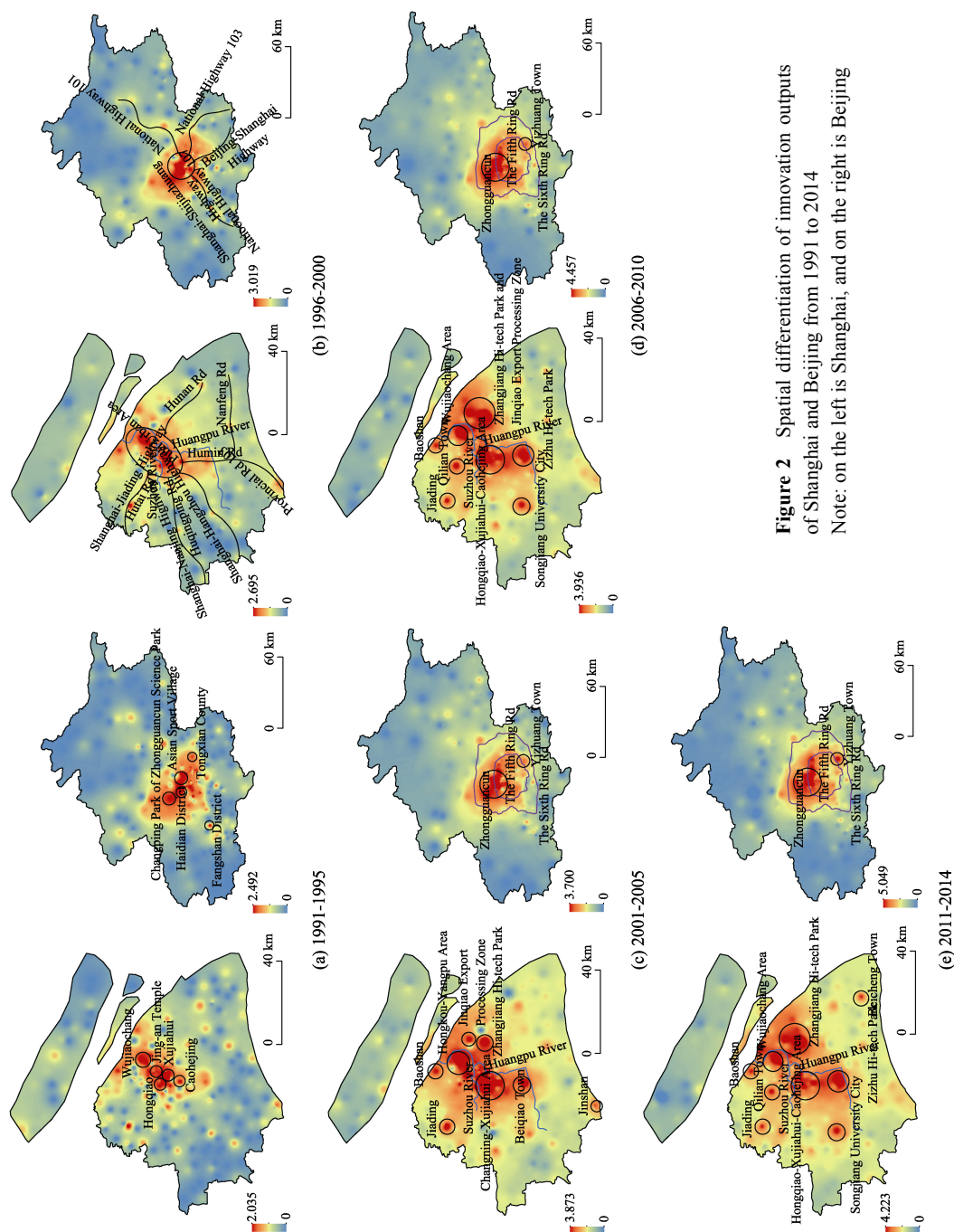
Table 2 Statistical characteristics of innovation outputs of Shanghai and Beijing from 1991 to 2014

	1991–1995		1996–2000		2001–2005		2006–2010		2011–2014	
	Shanghai	Beijing	Shanghai	Beijing	Shanghai	Beijing	Shanghai	Beijing	Shanghai	Beijing
<i>R</i>	2.035	2.492	2.695	3.019	3.873	3.699	3.507	4.457	4.223	5.049
<i>S-D</i>	0.536	0.665	0.561	0.727	0.616	0.836	0.658	0.945	0.644	0.936
<i>V-C</i>	0.900	1.043	0.621	0.870	0.462	0.743	0.390	0.645	0.353	0.601
<i>G-C</i>	0.502	0.570	0.345	0.486	0.251	0.412	0.215	0.359	0.194	0.334
<i>M-I</i>	0.383	0.519	0.496	0.547	0.562	0.627	0.604	0.733	0.565	0.727

3.2 The evolution pattern of urban innovation spatial structure in Shanghai

Although the spatial agglomeration of innovation outputs in Shanghai has been reinforcing, it has been split up and reconfigured under the influence of the suburbanization transfer of innovation resources, especially universities and research institutions. The overall pattern of urban innovation spatial structure in Shanghai has shown a trend of moving to east and south, which was specifically demonstrated by the evolving mode of single-core drive to multi-core and multi-axis drive under the core-periphery structure. Meanwhile, with the continuous optimization of traffic network structure, the corridor diffusion mechanism of Shanghai innovation outputs has been highlighted (Figure 2).

During the period from 1991 to 1995, the highest value areas of innovation outputs in Shanghai basically gathered in the main city area, especially in Puxi Urban Area surrounded by South Zhongshan Rd, West Zhongshan Rd, North Zhongshan Rd, Handan Rd, Xiangyin Rd, Jungong Rd, Liping Rd, Yangshupu Rd, Mingda Rd and East Zhongshan Rd, including the Wujiaochang Area based on Fudan University and Tongji University, the Caohejing Area centered on Shanghai Normal University, East China University of Science and Technology



and Caohejing Hi-tech Development Zone, the Hongqiao Area focused on Hongqiao Development Zone, Donghua University and Shanghai Engineering Technology Science University, the Xujiahui Area based on Shanghai Jiaotong University, Shanghai University of Traditional Chinese Medicine, Engineering College of Shanghai University and Medical College of Fudan University, the Jing-An Temple Area cored on Tongren Hospital, Huashan Hospital and Huadong Hospital, etc. At the same time, some Shanghai suburbs also grew some extreme values with a point distribution, such as Baoshan Town, Waigaoqiao Free Trade Zone, Songjiang Industrial Zone, Nanhui Industrial Park and Jiading Industrial Zone.

From 1996 to 2000, the spatial distribution pattern of innovation outputs in Shanghai was a continuation of the previous stage, basically showing a core-periphery structure. And the extreme value areas of innovation outputs were still within the Middle Ring. But compared with the previous stage, the urban spatial units participating in innovation had increased rapidly from 170 to 228. The corridor diffusion mechanism of urban innovation had initially developed, with obvious dependence on urban traffic trunks, such as the diffusion channel composed by Humin Rd and Provincial Rd 103 from downtown to Minhang District and Jinshan District, the diffusion channel dependent on Humin Rd, Provincial Rd 103 and Nanfeng Rd from downtown to Minhang District, Fengxian District and Nanhui District, the diffusion channel dependent on Shanghai-Hangzhou Highway from downtown to Songjiang District and Fengjing Town, the diffusion channel relied on Shanghai-Nanjing Highway and Huqingping Rd from downtown to Qingpu District and Jinze Town, the diffusion channel constituted by Shanghai-Jiading Highway and Hutai Rd from downtown to Jiading District, the diffusion channel dependent on Hunan Rd from downtown to Zhangjiang Town and Nanhui District, and the diffusion channel dependent on Pudong Avenue from downtown to Jinqiao Export Processing Zone and Waigaoqiao Port Area.

From 2001 to 2005, the spatial distribution pattern of innovation outputs in Shanghai began to show a differentiation trend. The extreme value area of the innovation outputs concentrated within the Middle Ring had been split up into two areas due to the emergence of the fault zone based on Suzhou River, one was the Hongkou-Yangpu Area with Wujiaochang as the core; the other was the Changning-Xuhui Area based on Xujiahui, Caohejing and Hongqiao Area. With the implementation of the strategy of Focusing on Zhangjiang proposed by Shanghai Municipal Government in 1999 and the establishment of Shanghai International Medical Zone in 2003, Zhangjiang Hi-tech Park had become a new growth pole of Shanghai innovation outputs, and formed the innovation outputs' intensive area in Pudong New Area together with the Jinqiao Export Processing Zone. At the same time, due to the connection of Metro Line 1 and Line 5, the diffusion effects based on traffic corridors had been fully reflected at this stage. The regional innovation outputs along Metro Line 5 grew significantly, especially Beiqiao Town in Minhang District, had become another extreme area of Shanghai innovation outputs. In addition, driven by the beltway, the circle diffusion effect in Shanghai innovation outputs appeared, forming a ring zone of high value areas of innovation outputs.

From 2006 to 2010, with the increasing differentiation of Shanghai's innovation outputs spatial distribution, the fault zone in the last stage expanded into a swathe of innovation outputs within the Middle Ring. Meanwhile, in the background of a continuously polarizing Hongkou-Yangpu high intensity area located at the north of the Suzhou River, the internal differentiation of Changning-Xuhui high intensity area located at the south of the Suzhou

River occurred again. It had been divided into three groups of Caohejing, Xujiahui, and Hongqiao. With the successful development of Minhang Campus of Shanghai Jiaotong University, Minhang Campus of East China Normal University and Zizhu Hi-tech Park, innovation outputs extremum area in Minhang District had extended from Beiqiao Town to Tangwan Town and Wujing Town along the Huangpu River. During this period, under the development strategy of allocating innovation resources from a global perspective, Zhangjiang Hi-tech Park attracted a large number of well-known domestic and foreign enterprises, especially Multi-National Corporation R&D centers, such as GE, Roche, Novartis, Honeywell, etc. Among them, many R&D centers have been upgraded to Global R&D Centers. The continuous expansion of innovation outputs contributed to a radiation effect rising rapidly. Thus Zhangjiang Hi-tech Park became the dominant spatial unit of Shanghai's innovation outputs. Besides, Songjiang University City entered a period of rapid development from the initial stage. With the joint efforts of all universities in the University City, innovation outputs increased year on year, and Songjiang University City became a high intensity value area of Shanghai's innovation outputs. On the whole, the zero value areas in blocks of Shanghai had basically ceased to exist during this period, with Chongming Island becoming a new colony.

During the final stage from 2011 to 2014, the multi-core structure of Shanghai's innovation outputs deepened, innovation activities were substantially transferred from inside to outside of the Middle Ring, and the spatial structure led by Central City basically collapsed. Whereas an oblique "W-shaped" pattern of multi-core structure of Shanghai's innovation outputs formally came into being, Songjiang University Town, Zizhu Hi-tech Park, Xujiahui-Caohejing-Hongqiao Area, Zhangjiang Hi-tech Park and Wujiaochang Area were the five inflection points of the oblique "W-shaped" pattern of the multi-core structure. In this process, optimization of traffic flows played a very important role, because it was the expressways that connected the inflection points, such as the Shanghai-Jiaxing-Huzhou Expressway connecting Songjiang University Town and Zizhu Hi-tech Park, the Shanghai-Jinshan Expressway connecting Zizhu Hi-tech Park and Xujiahui Area, the Outer-Ring Expressway connecting Xujiahui Area and Zhangjiang Hi-tech Park, the Middle-Ring Expressway connecting Zhangjiang Hi-tech Park to Wujiaochang Area. Of course, the surrounding areas of these rapid transit corridors naturally became high value areas of innovation outputs.

3.3 The evolution pattern of urban innovation spatial structure in Beijing

Limited by terrain and under the continuous strengthening of spatial polarization trends, the spatial structure of innovation outputs in Beijing has basically been locked into a core-periphery structure led by downtown areas in the past 20 years. Innovation activities continued to occupy the space of downtown. During the gathering process of innovation activities, the urban innovation border gradually became clear (Figure 2).

In the first stage (1991–1995), there were only 144 spatial units participating in urban innovation. Like Shanghai, the highest value areas of innovation outputs in Beijing were basically in the main city area, extending from South Fifth Ring Rd to North Sixth Ring Rd. Having a large number of universities (Tsinghua University, Peking University, Renmin University of China, Beijing Jiaotong University, Beijing Normal University, Beijing

University of Posts and Telecommunications, Beihang University, University of Science and Technology Beijing, Beijing Institute of Technology, etc.), research institutions (Chinese Academy of Sciences, Chinese Academy of Agricultural Sciences, etc.) and hi-tech enterprises, Haidian District had undoubtedly become the paradise of innovation activities in Beijing. Meanwhile, driven by Changping Park's Zhongguancun Science Park, Changping County, as the northwest gate of Beijing, had become the innovation outputs' highest intensity region. And the industrial towns along National Highway 110 have been developed into a high value region. In addition, Fangshan District as the southwest gate, Tongxian County as the east gate, Miyun County and Shunyi County as the northeast gate of Beijing, all became the innovation outputs high value regions due to their location along these traffic routes.

During the second period, after the rapid increase in urban spatial units involved in innovation, the innovation outputs of the city also increased dramatically. Though the spatial structure of innovation outputs in Beijing formed in the first stage was not changed, the innovation activities of the peripheral area in Beijing increased significantly. At the same time, as some quick traffic corridors had opened to traffic, the spatial diffusion effect of innovation outputs in Beijing began to be highlighted, forming several pieces of a spatial radiation channel, such as the diffusion channel composed by Beijing-Shijiazhuang Highway and National Highway 107 from downtown to Fengtai District and Fangshan District, the diffusion channel dependent on Beijing-Shanghai Highway from downtown to Yizhuang Town and Majuqiao Town, the diffusion channel relied on National Highway 101 from downtown to Shunyi District and Miyun District, the diffusion channel relied on National Highway 103 from downtown to Tongzhou District, etc.

After 2001, the spatial structure of innovation outputs in Beijing was basically focused on the core-periphery structure led by downtown. After experiencing the process from diffusion (the tripartite development centered on Zhongguancun from 2001 to 2005) to agglomeration (the One Body and Two Wings Pattern centered on Zhongguancun from 2006 to 2010; a cluster development pattern dominated by Zhongguancun and Asian Games Village from 2011 to 2014), Zhongguancun, the core of innovation outputs' high intensity area, has gradually deepened its nuclear status. Meanwhile, driven by the Beijing Economic and Technological Development Zone, especially the Yizhuang Hi-tech Park of Zhongguancun, Yizhuang Town has gradually grown into an enclave of extreme value area of innovation outputs in Beijing. And because of the settlement of a large number of universities and research institutions, Tongzhou District has also become a hot spot for innovation activities. However, with the continuously high concentration of innovation resources in Zhongguancun and the Asian Games Village, the spatial diffusion effect of innovation outputs in Beijing has gradually weakened. In contrast, the circle locked-in effect based on Fifth Ring Rd became more prominent. Namely, by occupying a central area constantly, the spatial distribution of Beijing innovation activities has reflected a central gathering pattern with Fifth Ring Rd as the boundary.

4 Spatial correlation of innovation outputs

4.1 Common features of Shanghai and Beijing

The spatial scale dependence of knowledge spillovers and the scale effect of the industrial

economy determine that the spatial distribution of innovation activities is bound to follow the law of distance decay, showing an agglomeration pattern around the extreme value of innovation outputs. However, the overall differentiation of innovation outputs can only reflect the two cities' spatial variation, but cannot uncover the spatial interaction and the correlation intensity. In order to explain the spatial correlation effect of the innovation outputs in Shanghai and Beijing, this paper uses the LISA to classify the spatial correlation and agglomeration evolution of innovation outputs into four types: the first is High-High agglomeration (H-H) where both zip code districts and their neighbors have high outputs of innovation; the second is called High-Low agglomeration (H-L), zip code districts which have high outputs of innovation but with low outputs in their neighboring districts; the third is Low-Low agglomeration (L-L), where both zip code districts and their surrounding districts have low outputs of innovation; the fourth is Low-High agglomeration (L-H), in which zip code districts' outputs are low but their neighbors' are high.

During the past 25 years, both in Shanghai and Beijing, the innovation outputs distribution all presents a significant agglomeration effect, the spatial distribution of each type basically tends to flock together. Among them, H-H agglomeration types are distributed as clusters in the downtown of the two cities throughout the study period, showing a property of spatio-temporal inertia. L-L agglomeration types, evolving from dispersed blocks to continuous blocks, are basically gathered in the outer regions of the two cities. L-H agglomeration types are mainly found in the area near H-H agglomeration types, with a sporadic-like distribution. But their territory has been severely eroded, showing a trend towards extinction. H-L agglomeration types are scattered in the surrounding areas of L-L agglomeration types, with a chain-like continuous distribution. However, affected by the transfer of innovation resources, H-L agglomeration types are also close to extinction (Figure 3).

4.2 Spatial correlation and agglomeration evolution of Shanghai innovation outputs

From 1991 to 2014, the spatial correlation in Shanghai innovation outputs is significant. Under the migration trend of shifting of innovation resources to east and south, the spatial correlation effects of Shanghai innovation outputs also appear as a central hollow phenomenon (Figure 3). Due to the time-space differences of innovation outputs distribution, the spatial distribution of H-H agglomeration types has differentiated into a dual-core pattern from the single-core pattern led by the downtown, obviously forming two high-value plates: one includes Hongqiao Area, Xujiahui Area, Xinzhuang Area and Zizhu Hi-tech Park; the other is composed of Zhangjiang Hi-tech Park, Jinqiao Export Processing Zone, Wujiaochang Area and Waigaoqiao Area. The region within the Inner Ring Rd has gradually degraded from H-H agglomeration types to types with no characteristics. The growth of L-L agglomeration types shows good spatial dependence, basically distributing in the city suburbs, such as Chongming Island, Qingpu District, Jinshan District as well as Nanhui District. Among these, Chongming Island basically fell into L-L agglomeration types in 2005, and this pattern has not been changed by the end of this study period. Though the number of L-L agglomeration types in Qingpu District and Jinshan District is decreasing year by year, the spatial distribution pattern has experienced an alternate evolution trend from differentiation to agglomeration. The growth of L-L agglomeration types in Nanhui District shows the

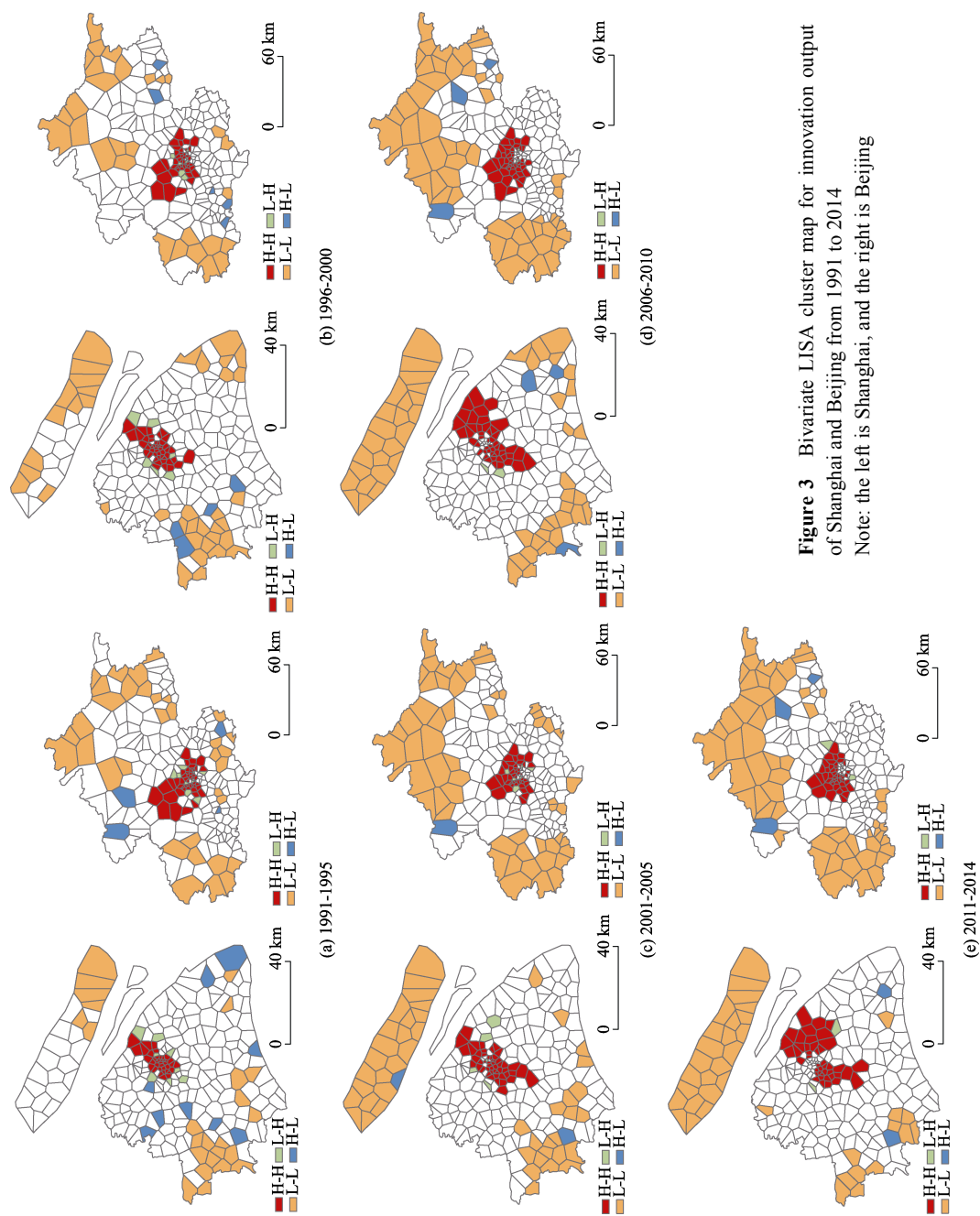


Figure 3 Bivariate LISA cluster map for innovation output of Shanghai and Beijing from 1991 to 2014
Note: the left is Shanghai, and the right is Beijing

jumping features in time sequence. In the first, third and fifth stages of this study, there were only a small number of L-L agglomeration types, showing a scattered and dispersed distribution pattern. However, in the second and fourth stages, there was a huge increase in the number of L-L agglomeration types, showing a continuous sheet-like distribution in space. The number and spatial distribution of L-H agglomeration types and H-L agglomeration types are largely influenced by the suburbanization trend of innovation resources. The chain-like encirclement of L-H agglomeration types was gradually broken through by H-H agglomeration types, and basically ceased to exist in 2014. Similarly, the spatial position of H-L agglomeration types continues to retreat from the middle circle to the periphery of Shanghai, and in the evacuation process, the territories of H-L agglomeration types are constantly lost. Towards the end of this research period, H-L agglomeration types are also approaching extinction.

4.3 Spatial correlation and agglomeration evolution of Beijing innovation outputs

Compared with the suburbanization trend of innovation resources in Shanghai, the direction of Beijing's innovation resources is shifting the other way round, showing a significant polarization trend. During the past 25 years, the spatial agglomeration evolution of innovation resources in Beijing shows a landscape pattern using the rural areas to encircle the cities (Figure 3). H-H agglomeration types gradually shrink towards the inner city. In order to occupy the few blocks of territories of L-H agglomeration types in downtown, H-H agglomeration types would rather sacrifice their outlying areas. And the overall spatial distribution has developed from dispersion in the first stage to blocks in last stage, showing a strong spatial cohesion and an efficient internal innovation spillover mechanism. Relatively, although L-L agglomeration types originated in peripheral areas (such as the West Mountain Area, Jundu Mountain Area and Wuling Mountain Area) and were still in fragmented form in 2000, their spatial growth shows a significant tendency towards the inner city after 2000. Compared with the gigantic and vigorous evolution trend of H-H agglomeration types and L-L agglomeration types, L-H agglomeration types and H-L agglomeration types keep a relatively low profile. In particular, as the frontier battlefield for innovation space competition, not only does the number of L-H agglomeration types decreases, but also their spatial location has also been pushed out of the downtown area. H-L agglomeration types are located in the buffer zone, which is adjacent to L-L agglomeration types. Due to the less creative power of L-L agglomeration types, the treatment suffered by H-L agglomeration types is relatively mild, and the spatial evolution also shows a spatio-temporal stability.

5 Conclusions and discussions

5.1 Conclusions

Having not changed with the adjustment of administrative divisions, zip code geodatabase provides a new perspective to study the spatial structure of urban innovation outputs from the urban internal scale. In this paper, the spatial point data of zip code in Shanghai and Beijing are constructed by randomly connecting edge points and the two cities' zip code geodatabase are divided by the Tyson polygon method. The results of this paper suggest that these

methods are effective and worth spreading.

(1) During the past 25 years, there have been many commonalities in the growth of urban innovation spatial structure between Beijing and Shanghai: on the statistical distribution of urban innovation outputs portrayed by *V-C* and *G-C*, both cities show a development trend from low-level agglomeration to optimized balanced distribution; on the oscillation amplitude of urban innovation outputs characterized by *R* and *S-D*, both cities present a violent oscillation trend; on the spatial distribution of urban innovation outputs depicted by *M-I*, both cities show a significantly positive spatial correlation, and the degree of spatial agglomeration has been increasing; on the spatial correlation and agglomeration evolution of urban innovation outputs described by LISA, the spatial distribution of each type basically tends to flock together.

(2) During the past 25 years, there are also many differences in the innovation spatial structure between Beijing and Shanghai: influenced by the suburbanization transfer trend of innovation resources, the overall pattern of urban innovation spatial structure in Shanghai shows a development trend moving to east and south. The detailed performances are that the evolution mode of Shanghai innovation spatial structure has experienced a growth process from single-core driven development to multi-core and multi-axis driven development. Accordingly, the spatial correlation effects of Shanghai innovation outputs appear as a central hollow phenomenon. As for Beijing, limited by terrain and under the continuous strengthening of spatial polarization trends, the spatial structure of innovation outputs has been basically locked into the core-periphery structure led by downtown in the past 25 years, and the spatial agglomeration evolution of innovation resources in Beijing shows a landscape pattern using the rural areas to encircle the cities.

(3) The balanced and non-balanced laws of spatial distribution of innovation activities in the inner city are closely related to the regional (above the city scale) innovation pattern. The balanced development of innovation activities and resources in the Yangtze River Delta urban agglomeration has an endogenous complementarity with the suburbanization trends of Shanghai innovation resources, and the trend of spatial polarization of innovation resources in Beijing-Tianjin-Hebei metropolitan region appears to be clearer in the city of Beijing, which means that the innovation spatial structures between region scale and city scale have an inherent consistency. Compared to the single-core structure in Beijing-Tianjin-Hebei metropolitan region, the coordinated development of urban innovation has made the Yangtze River Delta urban agglomeration more competitive in global science and technology development. According to the Innovation Cities™ Index 2014, Shanghai is the only city in mainland China that sits on the Nexus classification, with a ranking of 35. Moreover, Nanjing, Suzhou and Hangzhou are also on the list, respectively, ranking 127, 182 and 208 in the world. Among them, Nanjing also occupies the hub classification that is the same as Beijing. By contrast, Tianjin, another core city of Beijing-Tianjin-Hebei metropolitan region, always falls behind, with a rank of 234.

5.2 Discussions

Although the spatio-temporal growth patterns of urban innovation spatial structure can be realized by city zip code geodatabase from city internal scale, limited by the caliber and encoding of statistical data, only papers and patents can be identified through searching the zip

code. The data comes under the classification of innovation outputs, which limits the focus of this paper to studying the development of urban innovation spatial structure from the perspective of innovation outputs. The city innovation system is a giant and complex system. Although the spatial evolution of urban innovation structure can be explained to some extent from the perspective of innovation outputs, it is still not enough. How to get the best of both sides (research scale and evaluation index) is a subject worthy of further research.

Taking papers and patents as the evaluation indicators, this study acknowledges the key function of universities and research institutions in shaping the spatial structure of urban innovation to a large extent. Applications for invention patents can reflect the effectiveness of enterprises participating in innovation to some extent, but it is not enough. Scientific research is the process of turning money into knowledge, and innovation is the process of turning knowledge into money, which was proposed by Zhang Shousheng, a professor from Stanford University at the Sino-US Startup & Entrepreneur China Media Annual Conference in 2014. So innovation should be a market-oriented behavior, and enterprises should become the dominant actors in innovation. Therefore, how to construct the spatial database including the innovation ability of the enterprise based on zip code is a problem worthy of further consideration.

References

- Berger L, Benschop Y, van den Brink M, 2015. Practising gender when networking: The case of University-Industry Innovation Projects. *Gender Work and Organization*, 22(6): 556–578.
- Cheng Hua, Liao Zhongju, Dai Juanlan, 2011. The research on the coordination between China regional environment innovation ability and economy development. *Economic Geography*, 31(6): 985–991. (in Chinese)
- Cheng Yeqing, Wang Zheyue, Ma Jing, 2014. Analyzing the space-time dynamics of innovation in China. *Acta Geographica Sinica*, 69(12): 1779–1789. (in Chinese)
- Chen Xiuying, Chen Ying, 2012. The regional differences of science and technology resources and the allocation efficiency evaluation in Zhejiang province. *Scientia Geographica Sinica*, 32(4): 418–425. (in Chinese)
- Du Debin, 2014. The eve of a major reshuffle: Asia, the destination of the fifth transnational shifting of global innovation resources. *Shanghai: Oriental Morning Post*, 2014-10-14. (in Chinese)
- Du Debin, 2015. Global S&E Innovation Center: Motivation and Model. Shanghai: Shanghai People's Publishing House. (in Chinese)
- Du Debin, Duan Dezhong, 2015. Spatial distribution, development type and evolution trend of global S&E innovation center. *Shanghai Urban Planning Review*, (1): 76–81. (in Chinese)
- Fan Bonai, Duan Zhongxian, Jiang Lei, 2013. The effect and spatial-temporal differences of Chinese independent innovation policy: Evidences from provincial panel data. *Economic Geography*, 33(8): 31–36. (in Chinese)
- Fan Fei, Du Debin, Li Heng *et al.*, 2013. Spatial-temporal characteristics of scientific and technological resources allocation efficiency in prefecture-level cities of China. *Acta Geographica Sinica*, 68(10): 1331–1343. (in Chinese)
- Fang Chuanglin, Ma Haitao, Wang Zhenbo *et al.*, 2014. Comprehensive assessment and spatial heterogeneity of the construction of innovative cities in China. *Acta Geographica Sinica*, 69(4): 459–473. (in Chinese)
- Felsenstein D, 2015. Factors affecting regional productivity and innovation in Israel: Some empirical evidence. *Regional Studies*, 49(9): 1457–1468.
- Geroski P A, 1990. Procurement policy as a tool of industrial policy. *International Review of Applied Economics*, (2): 182–198.
- Guastella G, van Oort F G, 2015. Regional heterogeneity and interregional research spillovers in European innovation: Modelling and policy implications. *Regional Studies*, 49(11): 1772–1787.
- Hu Shuhong, Du Debin, You Xiaojun *et al.*, 2014. Spatial-temporal evolution analysis on knowledge innovation performance of universities in China's "Growth Triangle Regions". *Economic Geography*, 34(10): 15–22. (in Chinese)
- Jiang Tianying, 2014. Spatial differentiation and its influencing factors of regional innovation output in Zhejiang province. *Geographical Research*, 33(10): 1825–1836. (in Chinese)
- Lei Liang, Xu Jiqin, Ying Miaohong, 2015. Spatial differentiation and temporal evolution of regional innovation:

- Taking the counties in Zhejiang province as an example. *Science-Technology and Management*, 17(1): 24–29. (in Chinese)
- Li Dandan, Wang Tao, Wei Yehua *et al.*, 2015. Spatial and temporal complexity of scientific knowledge network and technological knowledge network on China's urban scale. *Geographical Research*, 34(3): 525–540. (in Chinese)
- Li D D, Wei D Y H, Wang T, 2015. Spatial and temporal evolution of urban innovation network in China. *Habitat International*, (49): 484–496.
- Li Jin, Deng Feng, 2013. Research on the influence mechanism of government investment in R&D subsidies on technology innovation output capacity: Empirical analysis based on panel data of 5 high-tech industries. *Science & Technology Progress and Policy*, 30(13): 67–71. (in Chinese)
- Lim U, 2003. The spatial distribution of innovative activity in U.S. metropolitan areas: Evidence from patent data. *Journal of Regional Analysis and Policy*, 33(2): 84–126.
- Liu Hedong, 2010. Research on spatial agglomeration of original innovation output of China's region. *Journal of Industrial Technological Economics*, (11): 122–128. (in Chinese)
- Liu Liying, 2010. Research on industry development from perspective of innovation in the districts and countries of Tianjin [D]. Tianjin: Tianjin University. (in Chinese)
- Lyu Guoqing, Zeng Gang, Guo Jinlong, 2014. Innovation network system of industry-university-research institute of equipment manufacturing industry in the Changjiang River Delta. *Scientia Geographica Sinica*, 34(9): 1051–1059. (in Chinese)
- Lyu Lachang, He Ai, Huang Ru, 2014. Beijing's urban innovational function based on knowledge output. *Geographical Research*, 33(10): 1817–1824. (in Chinese)
- Lyu Lachang, Liang Zhengji, Huang Ru, 2015. The innovation linkage among Chinese major cities. *Scientia Geographica Sinica*, 35(1): 30–37. (in Chinese)
- Niu Fangqu, Liu Weidong, 2012. Relationships between scientific & technological resources and regional economic development in China. *Progress in Geography*, 31(2): 149–155. (in Chinese)
- Makkonen T, Inkinen T, 2014. Innovation quality in knowledge cities: Empirical evidence of innovation award competitions in Finland. *Expert Systems with Applications*, (41): 5597–5604.
- Moreno R A, Paci R B, Usai S B, 2005. Spatial spillovers and innovation activity in European regions. *Environment and Planning A*, 37(10): 1793–1812.
- Su Fanglin, 2006. Analysis on the spatial pattern of China's provincial R&D spillovers. *Studies in Science of Science*, (5): 696–701. (in Chinese)
- Tao Xuefei, 2013. Evaluation index system of a city's comprehensive ability of S&T innovation. *Economic Geography*, 33(10): 16–19. (in Chinese)
- Wang Bei, Liu Weidong, Lu Dadao, 2011. Allocation efficiency of science and technology resources in Jing-Jin-Ji, Yangtze River Delta and Pearl River Delta regions. *Progress in Geography*, 30(10): 1233–1239. (in Chinese)
- Wang Chunyang, Zhao Chao, 2014. Spatial-temporal pattern of prefecture-level innovation outputs in China: An investigation using the ESDA. *Scientia Geographica Sinica*, 34(12): 1438–1444. (in Chinese)
- Wang Jici, 1999. Knowledge innovation and regional innovation environment. *Economic Geography*, 19(1): 11–15. (in Chinese)
- Yang Bixia, 2007. Research on the joint development of scientific and technological innovation and regional economy in Shanghai [D]. Shanghai: Tongji University. (in Chinese)
- Yu Junbo, Shu Zhibiao, 2007. An empirical study on the relationship between enterprise scale and innovation output. *Studies in Science of Science*, 25(2): 373–380. (in Chinese)
- Zhang H Y, 2015. How does agglomeration promote the product innovation of Chinese firms? *China Economic Review*, (35): 105–120.
- Zhang Yuming, Li Kai, 2007. Research on the spatial distribution and dependence of Chinese innovative output: Spatial econometrics analysis based on province-level patent data. *China Soft Science*, (11): 97–103. (in Chinese)
- Zhang Zhanren, 2013. Regional linkage and spatial spillover effects on regional innovation development in China: A case study from the perspective of economic innovation transformation in China. *Studies in Science of Science*, (9): 1391–1398. (in Chinese)
- Zhou Shangyi, Lyu Guowei, Dai Juncheng, 2011. An analysis of the relation between the enterprise network characteristics and their innovation capabilities in the space of DRC on Beijing. *Economic Geography*, 31(11): 1845–1850. (in Chinese)
- Zhu Huasheng, Wu Junyi, Wei Jiali *et al.*, 2010. Creative networking in developing countries: A case study of design industry in Shanghai, China. *Acta Geographica Sinica*, 65(10): 1241–1252. (in Chinese)
- Zhu Ying, Du Debin, 2005. The spatial organization of R&D globalization by multinational corporations. *Economic Geography*, 25(5): 620–623. (in Chinese)