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Spatial evolution of urban innovation outputs in a Zip-code area scale: An comparative analysis of Shanghai and Beijing in China

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Abstract: To date, technological innovation plays a vital role in national powers and social advances, and garners extensive attention from many disciplines. Few studies have focused on spatial analysis of urban innovation, a minority of which have documented on a fine scale from comparative and dynamic perspectives. Based on academic papers and patents in Zip-code areas, evolving similarities and differences in urban innovation outputs between the two municipalities of Shanghai and Beijing from 1991 to 2014 were spatially depicted by using Spatial Autocorrelation Analysis and Kernel Density Estimation. During the 25 year study period, some structural similarities relating to the spatial evolution of the two municipality innovation are observed, including increasing disparities and polarization, and emerging agglomeration and expansion, as well as a stable core-peripheral pattern consisting of hot spots (or high-high clusters) in their downtowns and cold spots (low-low clusters) in their outer suburbs. Meanwhile, other differences between them are considerable, including mainly two important findings. The first is related to a clustering pattern on the whole. Specifically, the distribution of innovation outputs in Shanghai is evolving from an initial monocentric pattern to polycentric clusters under recent high-speed suburbanization of residential areas and industrial zones. Clearly, radial expansion or belt-shaped diffusion along arterial streets and metro lines was prominent as well, which results gradually in a dual-core structure (downtown and Zhangjiang Hi-tech Park) with multiple secondary centers. In contrast to Shanghai, Beijing's innovation outputs exhibit a concentric pattern, with high-outputs areas persistently locked in its urbanized regions, particularly in Zhongguancun Science Park.

Keywords: innovation outputs; Zip-code area; spatial evolution; similarities and differences; clustered and dispersed pattern

1 Introduction

Nowadays, technological innovations have emerged as an important source of competitive strength (Tirupati, 2008; Du, 2015) and not only do they serve as a significant competitive tool (Chataway *et al.* 2007), but also play a vital role in improving the firm's performance (Dasgupta *et al.*, 2011). Since the 21st century, a wave of scientific and technological revolution has become one of the ascendant factors resulting in rapid shifting in the global political and economic landscape. In detail, high-end production factors and innovation elements have been increasingly transferred to the Asia-Pacific region, giving rise to the emergence of new world-class metropolises associated with technological innovation (or global technology innovation centers),

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particularly in China with its abundant talent and rapidly growing market (Du, 2014; Du *et al.*, 2015). According to the Innovation Cities™ Index (2009-2014), Shanghai and Beijing have risen to become Pivot or Hub global innovation cities.

Since innovation theory was first introduced from the perspective of economics (Schumpeter, 1912), geographers and researchers from related disciplines have devoted a large amount of attention to the geographical analysis of innovation-related industries and activities. This research can be found in the literature on spatial distribution and patterns (Lim, 2003; Zhang *et al.*, 2007; Liu, 2010; Wang *et al.*, 2014; Jiang, 2014), regional effects and influences (Geroski, 1990; Yu *et al.*, 2007; Fan *et al.*, 2013; Li *et al.*, 2013; Felsenstein, 2015), spatial evolution and mechanism (Tao, 2013; Fang *et al.*, 2014; Makkonen *et al.*, 2014; Wang *et al.*, 2011; Chen *et al.*, 2012; Fan *et al.*, 2013; Cheng *et al.*, 2014), network structure and organization (Zhu *et al.*, 2005; Zhang, 2015; Lyu *et al.*, 2015; Lyu *et al.*, 2014; Li *et al.*, 2015; Li *et al.*, 2015; Berger *et al.*, 2015), etc. Most of these studies are well documented as follows: The first is related to an evaluation system of urban innovation, including innovation inputs, innovation outputs, innovation environment, and so on through field surveys, telephone interviews and questionnaire surveys, etc. (Fan *et al.*, 2013; Tao *et al.*, 2013; Cheng *et al.*, 2014; Fang *et al.*, 2014). Many studies used patent data (application or granted) to measure urban or regional innovation outputs (Zhang *et al.*, 2007; Liu, 2010; Jiang, 2014; Wang *et al.*, 2014). Due to a lack of both funding and data, fewer studies focused on a comprehensive evaluation of innovation capacity or ability, except for a few reports led by some think tanks or decision-making consultancies. For example, 2thinknow, an Australian institution, constructed a systematic assessment of global innovation cities using 162 indicators relating to Cultural Assets, Human Infrastructure and Networked Market, etc. (Fang *et al.*, 2014). Spatial inequality of innovation activities was also examined. The scale used in this research ranged from global to national or subnational, to urban and even to county-level. Some spatial statistical models such as *Moran's I Index*, *Location Gini Coefficient*, *Lorenz Curve*, *Coefficient of Variation* were used to measure disparities or clustering intensities (Lim, 2003; Zhang *et al.*, 2007; Liu, 2010; Wang *et al.*, 2014; Jiang, 2014), and further indicated uneven and clustering distributions of innovation activities, which was consistent with a scale-free statistical property. Thirdly, extensive evidence of the spatial spillover effects of regional innovation were found (Moreno *et al.*, 2005; Su, 2006; Zhang, 2013; Guastella *et al.*, 2015). There was a significant correlation and spatial diffusion of innovation activities among regions. Unlike the scale-free dependency of spatial distribution of innovation activities, there was a spatial constraint due to geographical proximity in knowledge spillover to some extent (Lei, 2015). Fourthly, mechanisms influencing innovation activities were also analysed. Some studies used regression models to reveal such influencing factors of spatial differences as innovation policies, foreign direct investment (FDI), enterprise scale, industrial clusters and innovation environment, etc. (Geroski, 1990; Yu *et al.*, 2007; Fan *et al.*, 2013; Li *et al.*, 2013; Felsenstein, 2015). Fifthly, were studies evaluating innovation ability and efficiency. Studies of regional innovation ability are mainly done by implementing a comprehensive evaluation model to map difference between cities, regions and provinces (Tao, 2013; Fang *et al.*, 2014; Makkonen *et al.*, 2014). The evaluation of regional innovation efficiency was usually conducted by input-output analysis to compare the efficiency of innovation activities at different scales (Wang *et al.*, 2011; Chen *et al.*, 2012; Fan *et al.*, 2013; Cheng *et al.*, 2014). The fifth is the relationship between innovation level and regional development, which has been the focus of many scholars since the 1990s. Based on a

comprehensive evaluation of the regional innovation system and development level, a series of correlational models were used to depict spatial assortativity or mismatch between regional innovation and socioeconomic development (Wang, 1999; Cheng *et al.*, 2011; Niu *et al.*, 2012). Lastly, network science was widely introduced to portray the regional connectivity of innovation networks in recent years. In the absence of scale diversities such as global, national, and subnational scales, related research methods and perspectives were multiple, including examining the spatial structure of global R&D networks (Zhu *et al.*, 2005; Zhang, 2015), regional intensity and patterns of innovation contact based on the spatial gravity model (Lyu *et al.*, 2015), and geo-complexity of regional innovation networks based on social network analysis (Lyu *et al.*, 2014; Li *et al.*, 2015; Li *et al.*, 2015; Berger *et al.*, 2015).

Despite the increasing importance of innovation geography research, several problems associated with spatial scale, administrative boundaries and data processing have not been fully addressed. Firstly, those at the medium and macro scales such as global, national and subnational levels are better described by a number of studies than are those at the local or urban scale, which makes structural optimization of regional innovation industries difficult to implement because of transboundary nature of administrative jurisdiction. Secondly, most case studies used some areal units with administrative boundaries, with uncertain data resulting from shifting administrative divisions. Thirdly, due to difficulties in obtaining related data at local or fine scales (i.e. subdistricts, towns or villages), research with the following perspectives were more common: (1) taking some innovative subjects such as the enterprises, colleges, universities and other scientific research institutions as the research objects and looking at their innovation ability and efficiency (Hu *et al.*, 2014); (2) choosing hi-tech parks or creative industrial zones as an example to portray innovation spillover effects, innovation efficiency, spatial organization and impacts on regional economic development (Zhu *et al.*, 2010; Zhou *et al.*, 2011); (3) focusing on knowledge production to analysis functions of the urban innovation system (Lyu *et al.*, 2014); (4) taking urban administrative divisions as areal units to depict the impacts of innovation investments or outputs on economic development (Yang, 2007; Liu, 2010).

To address the problems, a Zip-code geodatabase associated with innovation outputs in the two megacities was implemented to provide a new perspective to highlight their spatiotemporal similarities and differences. Its contribution is twofold. Firstly, based on the stable Zip-code geodatabase, some finer-scale images and variations are better visualized in a more microcosmic scale, which can avoid the effects of the frequent reform of China's administrative divisions. Secondly, a comparative analysis between Shanghai and Beijing is conducted to reveal the main similarities and differences in relation to spatial disparities and variations of scientific papers and patents in magnitude Zip-code areas, as well as the possible reasons for these.

To this end, the remainders of this paper are organized as follows. Section 2 describes the data and methodology. In Section 3, the spatial pattern and the evolution model of 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 includes the conclusion, lists future tasks to be explored.

2 Research methods

2.1 Data preparation

Because of the uncertain range of each real Zip-code region, a simulation method is implemented

to divide their approximate range. Based on the Zip code address data in China Post Media Data Center, this paper takes the areal unit addresses of each Zip code as the modified basis for constructing the Zip-code geodatabase of Shanghai and Beijing as follows:

First of all, 10% unit addresses of each Zip code are randomly selected and geocoded on Baidu Map. Secondly, they are connected to determine the range of the Zip-code area. Then, 5% of the remaining units are further randomly attracted to identify their location. If they are all in this region, the range will be regarded as the area represented by the Zip code; otherwise, the second and third steps need to be repeated. Finally, the geometric center of each Zip-code area is taken as one of the real Zip-code region. As a result, 249 pieces of Zip-code areas in Shanghai and 239 of Beijing are interpolated using *Tyson Polygon Method* to construct the Zip-code geodatabase, as shown in Figure 1.

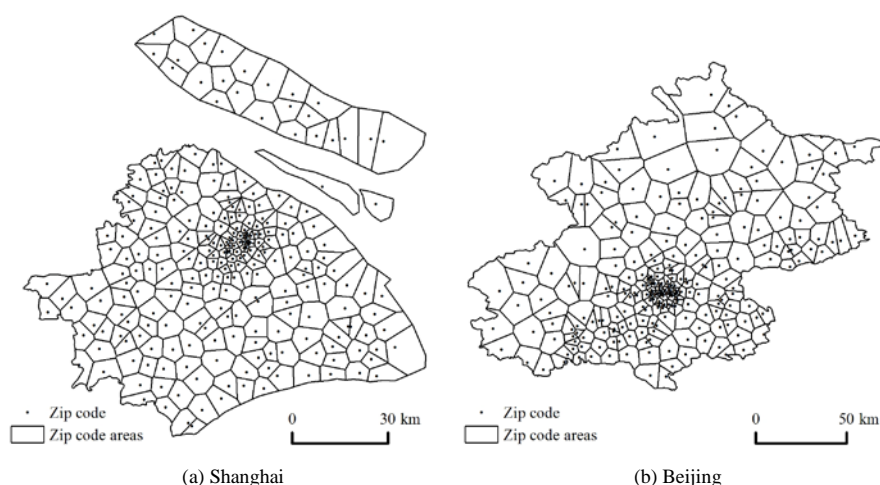


Figure 1 Zip code geodatabase of Shanghai and Beijing

2.2 Innovation outputs index

In this paper, two indicators “Number of Papers Issued in Important Journals” and “Invention Patent Applications” are introduced to indicate innovation outputs. The important journals are indexed by Chinese Social Sciences Citation Index (CSSCI), Chinese Science Citation Database (CSCD), Science Citation Index (SCI) and Social Sciences Citation Index (SSCI), and invention patent applications are taken from Wanfang Data Knowledge Service Platform of China and PCT data of the World Intellectual Property Organization (WIPO) (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
	Number of Zip code areas participating in innovation	170	228	246	249	248	/
Shanghai	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
	Number of Zip code areas Participating in innovation	144	179	212	231	236	/

Beijing	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

A *Cusp Catastrophe Model* is used to solve the urban innovation comprehensive index (Fan *et al.*, 2013):

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

where $f(x)$ is the potential function of state variable x . a , b indicates the control variables of the state variable x .

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

Because of the obvious complementarity between paper and patent indicators, we use an average value method to determine the value of each index and the comprehensive value.

2.4 Spatial autocorrelation analysis

In order to more precisely describe local pattern of urban innovation outputs, *Spatial Autocorrelation Model*, mainly addressed by Global Spatial Statistic Indexes and Local Indicators of Spatial Association (LISA) (Moran, 1948; Anselin, 1995), are used to spatially examine the clustering degree of innovaton outputs of Zip-code areas. Here, two Moran's I indices are introduced to depict the global aggregating distribution and the local aggregating center of urban innovation outputs, and defined as:

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

$$\text{local Moran's } I = \frac{(n-1)(X_i - \bar{X})}{\sum_{j=1, j \neq i}^n (X_j - \bar{X})^2} \sum_{j=1, j \neq i}^n W_{ij} (X_j - \bar{X}) \quad (4)$$

where, n is the size or number of all locations (spatial units). W_{ij} denotes a proximity matrix of weighted values, where elements are a function of distance from 0 to 1. X_i and X_j represent values of variables at locations i and j , respectively. \bar{X} is mean value of variable X_i or X_j . The two standardized equations result in Moran's I coefficients ranging from (-1) to (+1), where values between (0) and (+1) indicate a positive autocorrelation between locations, values between (0) and (-1) are negatively associated, and (0) indicates the values are spatially random. Additionally, local Moran's I is also used to estimate the degree of spatial autocorrelation between a given location and neighbors through their similarity and significance, in order to identify local clustering areas with both extreme and homogeneous values (called hot spots and cold spots). As a result, five scenarios may emerge through the LISA tool: hot spots (high-high locations with high values with similar neighbors), cold spots (low-low locations with low values with similar neighbors), high-low spatial outliers (locations with high values with low-value neighbors, low-high spatial outliers (locations with low values with high-value neighbors), and locations with no significant local autocorrelation.

3 Spatial evolution of urban innovation outputs

3.1 Statistical similarities between Shanghai and Beijing

To describe the statistical distribution of urban innovation outputs, a series of statistical models including *Range (R)*, *Standard Deviation (S-D)*, *Coefficient of Variation (V-C)*, *Gini Coefficient (G-C)*, and *Global Moran's I Index (M-I)* are introduced to explore distributive properties of urban innovation outputs (see Table 2).

During the last 25 years, both the *R* value of innovation output in Shanghai and Beijing have been enlarged gradually with a range from 2.035 and 2.492 in 1991 to 4.223 and 5.049 in 2014, respectively. In addition the *S-D* values have risen by as much as 0.536 and 0.665 to 0.644 and 0.936. These results indicate an increasing and greater degree of dispersion exhibiting a discrete distribution and evolving richer-club effect.

In terms of the *V-C* and *G-C*, both Shanghai and Beijing have 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, and the *G-C* descends from 0.502 and 0.570 to 0.194 and 0.334, which illustrates that the statistical distribution of innovation outputs presents a dispersing trend from low-level agglomeration to highly-balanced development.

In addition, the *M-I* of Shanghai and Beijing is respectively rising from 0.383 and 0.519 in 1991 to 0.565 and 0.727 in 2014. In both cities, the innovation outputs had significant positive correlations among Zip-code areas, and presented a strongly-clustered pattern. It is worth mentioning that, the five indices of Beijing are greater than Shanghai in all five periods. Compared with Beijing, Shanghai's decentralization trend of innovation outputs has been more 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 Spatial evolution of urban innovation outputs in Shanghai

Although spatial agglomeration of innovation outputs in Shanghai has been reinforcing, a spatial dispersion or expansion has been observed under the suburbanization of innovation resources such as universities and research institutions. The holistic pattern of urban innovation outputs has shown a trend of shifting towards the east and south of Shanghai and demonstrated a core-periphery structure with the variation from concentric agglomeration to polocentric clusters and multi-axis dispersion, which results from some radial traffic corridors (Figure 2).

During the first period from 1991 to 1995, the peak-value areas of innovation outputs in Shanghai basically concentrated in its urbanized or built-up areas, especially in western urban areas of Huangpu river 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. In which, most of these higher-outputs areas were heavily dependent on universities or institutions, for instance, the Wujiaochang area based on Fudan University and

Tongji University, the Caohejing area consisted of Shanghai Normal University, East China University of Science and Technology, and Caohejing Hi-tech Development Zone, the *Hongqiao* area including 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, as well as the Jing-an Temple area located by Tongren Hospital, Huashan Hospital and Huadong Hospital, etc. At the same time, some clusters with higher-level innovation outputs were interpolated in Shanghai's suburbs, interspersing in Baoshan Town, Waigaoqiao Free Trade Zone, Songjiang Industrial Zone, Nanhui Industrial Park and Jiading Industrial Zone, etc.

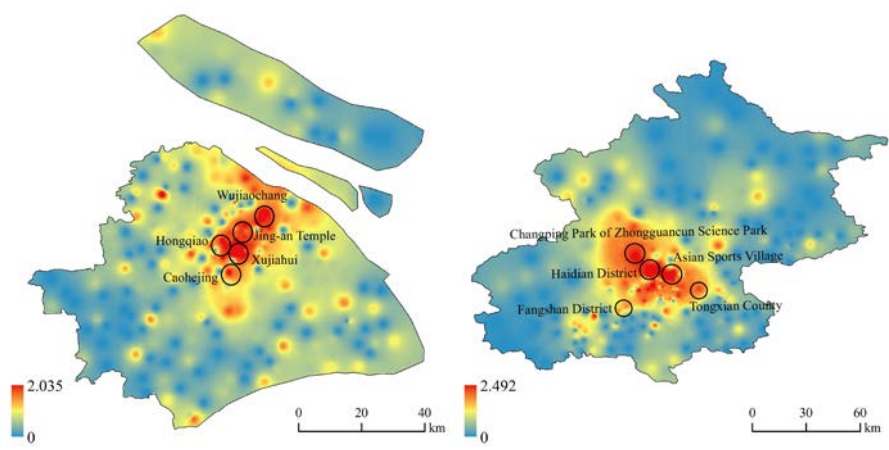
From 1996 to 2000, spatial pattern of innovation outputs in Shanghai was continuously exhibiting a core-periphery structure. The highest-value areas of innovation outputs were still place-dependent (Martin & Sunley, 2006) and locked within the Middle-ring expressway. Except for highly clustering in central urbanized areas, some of greater-level areas axially and radially expanded from its downtown to outer suburbs along main traffic corridors or arterial highways, primarily including seven diffusion axes: one was composed of Humin Rd. and Provincial Rd. 103 from downtown of Shanghai to Minhang District and Jinshan District, the second axis relied on Humin Rd., Provincial Rd. 103 and Nanfeng Rd. from the downtown to Minhang District, Fengxian District and Nanhui District, the third axis was dependent on Shanghai-Hangzhou Highway from the downtown to Songjiang District and Fengjing Town, the fourth was outspread along Shanghai-Nanjing Highway and Huqingping Rd. from the downtown to Qingpu District and Jinze Town, the fifth constituted by Shanghai-Jiading Highway and Hutai Rd. from the downtown to Jiading District, the sixth was consisted of Hunan Rd. from the downtown to Zhangjiang Town and Nanhui District, and the seventh expanded along Pudong Ave. from the downtown to Jinqiao Export Processing Zone and Waigaoqiao Port Area.

During the third period, differing from the first decade, spatial pattern of innovation outputs in Shanghai were polycentric. On the one hand, due to the separation of Suzhou River, the peak-value areas centralizing within the Middle-ring expressway had further been separated into dual-core areas--the Hongkou-Yangpu area taking Wujiaochang as its core and the Changning-Xuhui area based on Xujiahui, Caohejing and Hongqiao subareas. Because of the development of Zhangjiang led by Shanghai Municipal Government in 1999 and the establishment of Shanghai International Medical Zone in 2003, the Zhangjiang Hi-tech Park had become a new growth pole of Shanghai innovation outputs, and the peak-value area of Pudong new district together with the Jinqiao Export Processing Zone. Moreover, owing to Metro Line 1 and Line 5, the diffusion effects based on them had been fully discovered, in particular along Metro Line 5. For example, Beiqiao Town in Minhang District, a significant transfer station of metro lines, had become another hub of Shanghai innovative outputs. In addition, driven by the beltways such as the inner-ring expressway, the middle-ring expressway and the outer-ring expressway, the innovative outputs along them were evidently greater than surrounding areas.

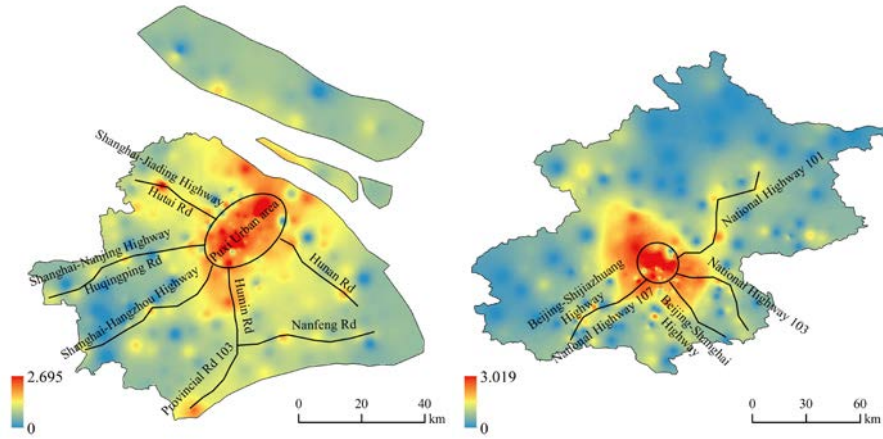
From 2006 to 2010, in central urban districts, in absence of increasing polarization of Hongkou-Yangpu peak-value area located in the northern Suzhou River, a obvious fragmentation was observed in Changning-Xuhui area of southern Suzhou River. It had been divided into three subgroups: Caohejing, Xujiahui, and Hongqiao. In some inner suburbs, particularly in Minhang district and Songjiang district, there were greater innovation outputs than other suburbs, because

of universities and institutions. Depending on the emergence of Minhang campuses of Shanghai Jiaotong University and East China Normal University and Zizhu Hi-tech Park, the cluster of innovation outputs in Minhang District extended from Beiqiao Town to Tangwan Town and Wujing Town along the Huangpu River. Recently, under the eastern shift of global innovation resources, Zhangjiang Hi-tech Park attracted a large number of well-known R&D institutions of transnational corporations, such as GE, Roche, Novartis, Honeywell, etc. Many of these were upgraded to the Global R&D Centers. As a result, it has become the new dominant areal unit of Shanghai's innovative outputs. Besides, the college town in Songjiang district had entered a secondary growth pole of Shanghai innovation outputs, because of a large number of universities and colleges. Additionally, some zero-value areas were observed, particularly located in Chongming Island, which is a restricted conservation area.

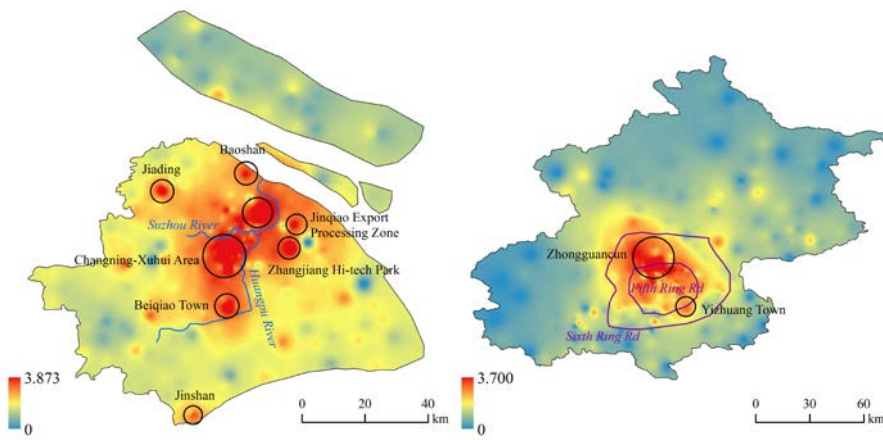
During the final stage, the polycentric structure of Shanghai innovation outputs was strengthened, innovation activities were substantially transferred to the periphery of the Middle-ring expressway or beltway, leading to structural fragmentation in the Central Shanghai. Whereas an oblique "W-shaped" structure of Shanghai innovation outputs had formally come into being, and Songjiang University Town, Zizhu Hi-tech Park, Xujiahui-Caohejing-Hongqiao Area, Zhangjiang Hi-tech Park and Wujiaochang Area were its five inflection points. Clearly, the construction of some expressways or highways connecting these points played a crucial role in the W-type structure, 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.



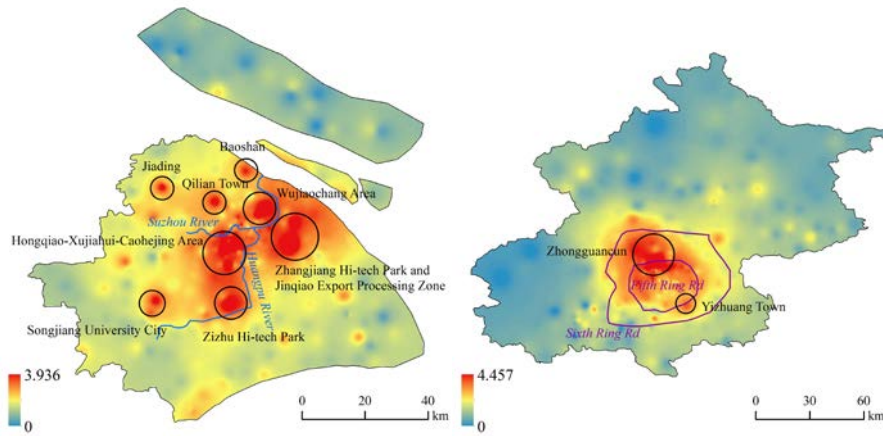
(a) 1991–1995



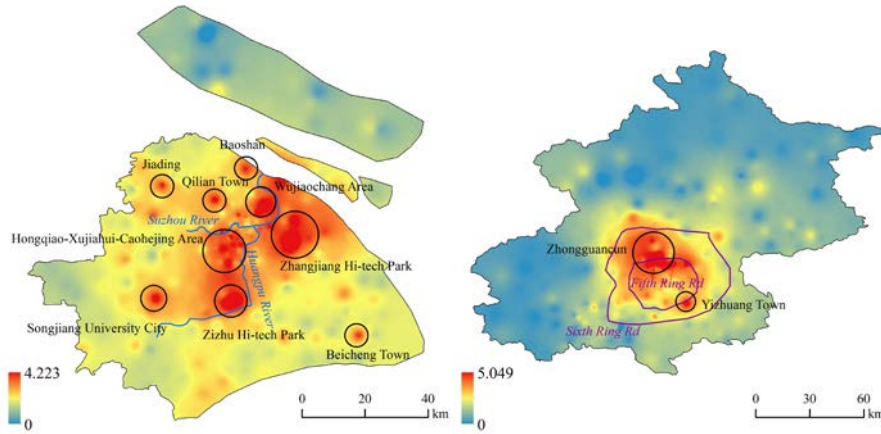
(b) 1996–2000



(c) 2001–2005



(d) 2006–2010



(e) 2011–2014

Figure 2 Spatial differences of innovation outputs in Shanghai and Beijing from 1991 to 2014

Note: on the left is Shanghai, and on the right is Beijing

3.3 Spatial evolution of urban innovation outputs in Beijing

Differing from the polycentric pattern of Shanghai's innovation outputs, urban innovation outputs in Beijing had a continuously concentric or monocentric distribution and exhibited a core-periphery structure led by its downtown in the past 20 years. To obtain some effects of scale economy, innovation activities have consistently clustered in the downtown (Figure 2).

In the first stage (1991–1995), there were only 144 areal units participating in urban innovation activities. Similar to Shanghai, the peak-value areas of innovation outputs in Beijing concentrated basically in its-built-up areas, extending from South Fifth-ring Rd. to North Sixth-ring Rd, especially in former Haidian district. These areas have a large number of universities (i.e. 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, and Chinese Academy of Agricultural Sciences, etc.) and hi-tech enterprises. Meanwhile, driven by Zhongguancun Science Park, Changping County, as the Northwest gate of Beijing, developed as the new upland of innovation outputs, including some industrial towns along the National Highway 110. In addition, Fangshan District as the Southwest gate, Tongxian district as the East gate, Miyun district and Shunyi district as the Northeast gate of Beijing, also had higher outputs due to their location close to arterial roads.

During the second period, after the rapid increase of Zip code area units involved in urban innovation, innovation outputs also expanded dramatically. Although the spatial structure was similar to the first stage, the intensity of innovation activities in the peripheral of Beijing increased significantly. At the same time, because of the completion of some radial highways or freeways, a radial diffusion pattern of innovation outputs along them was clearly reflected, and consisted of several radial axes including the Beijing-Shijiazhuang Highway and National Highway 107 from the downtown to Fengtai District and Fangshan District, the Beijing-Shanghai Highway connecting the downtown to Yizhuang Town and Majuqiao Town, and the National Highway 101 from the downtown to Shunyi District and Miyun District, as well as the National Highway 103 from the downtown to Tongzhou District, etc.

After 2001, the distribution of innovation outputs in Beijing was locked into a core-periphery

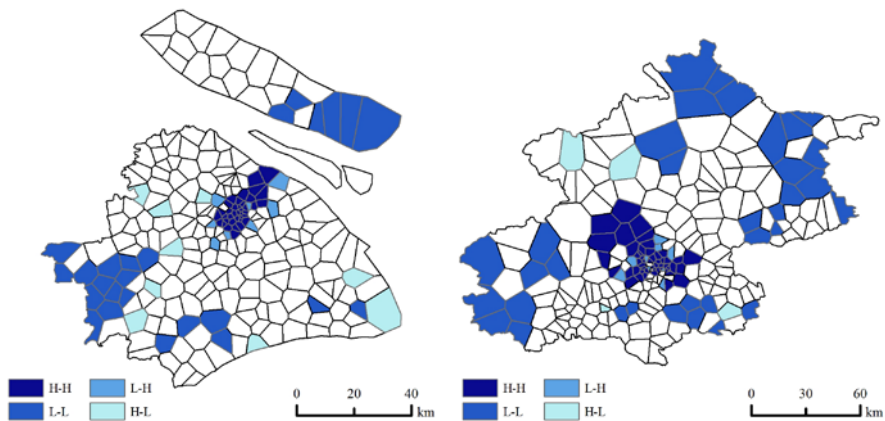
structure. Later it experienced the process from diffusion (the tripartite centers of Zhongguancun from 2001 to 2005) to agglomeration (the One Body and Two Wings Pattern in Zhongguancun from 2006 to 2010; the dual clusters were dominated by Zhongguancun and Asian Games Village from 2011 to 2014), Zhongguancun had gradually enhanced its position as the pivot of innovation outputs. Meanwhile, driven by the Beijing Economic and Technological Development Zone, especially the Yizhuang Hi-tech Park of Zhongguancun, Yizhuang Town rapidly became a new secondary hub of innovation outputs in Beijing. And because of the relocation of a large number of universities and research institutions, Tongzhou District had also become a hot spot of innovation activities. However, with the continuous centralization of innovation resources in Zhongguancun and Asian Games Village, the spatial diffusion effect of innovation outputs in Beijing was weakened. In contrast, a greater quantity of innovation activities was concentrated within the Fifth-ring expressway and exhibited a locked-in effect under the evolution of place-dependence.

4 Spatial autocorrelational analysis of urban innovation outputs

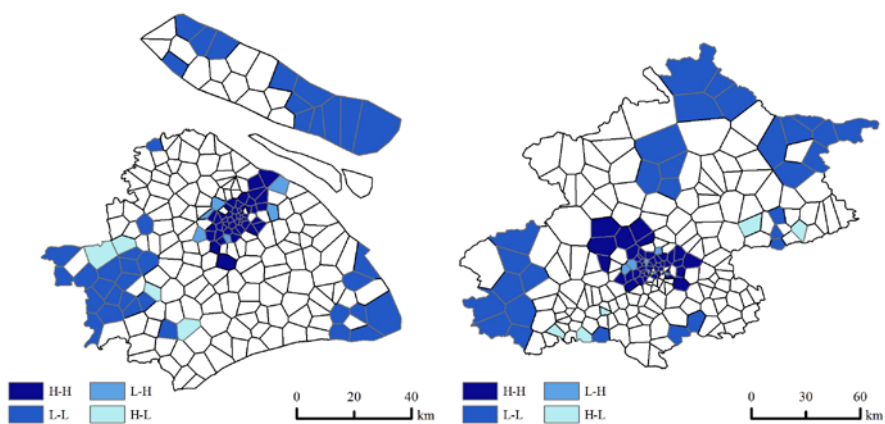
4.1 Similarities between Shanghai and Beijing

As explained earlier, the global Moran's I ranges of the two municipalities from 0.3 to 1, indicating a stronger positive spatial autocorrelation, with obviously similarities of variations and aggregating degrees. In order to further examine spatial clustering effect of the innovation outputs in Shanghai and Beijing, a LISA was used to identify their extent of spatial correlation and agglomeration of innovation outputs, a more precise assessment of localized spatial autocorrelation is needed.

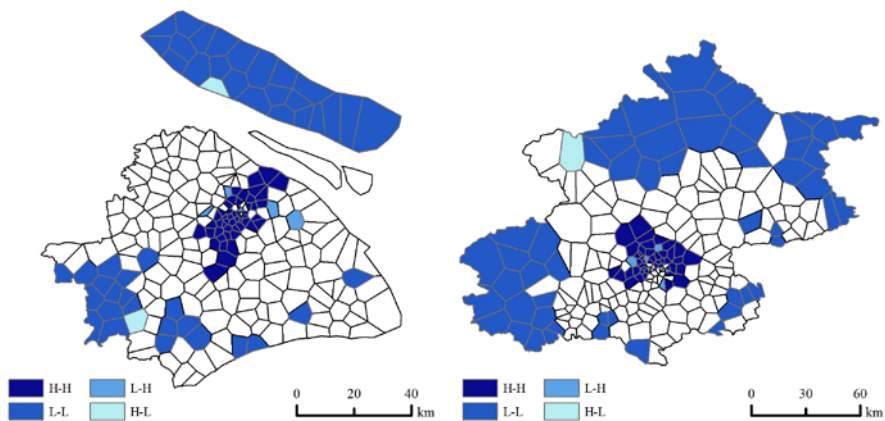
Figure 3 shows the location of Zip-code areas with statistically significant autocorrelation as well as the nature of spatial relationship between each Zip-code area and its neighbors (e.g. high-high outlier, low-low outlier, high-low outlier and low-high outlier types). During the past 25 years, both in Shanghai and Beijing, in absence of increasingly and strongly positive autocorrelation, the distributions of their innovation outputs present a more and more significant clustering effect, especially in high-high and low-low outliers. On the one hand, the distributions of hot spots and cold spots are place-dependent with temporal-spatial inertia. Among them, almost of hot spots or H-H outliers are locked as clusters in the downtown of the two cities over the period, and many of cold spots or L-L outliers are emerging in their outer suburbs, concentrating on Chongming county and Qingpu district of Shanghai as well as Huairou, Miyun and Fangshan districts of Beijing, which exhibits a stable core-peripheral structure. Differently, L-H outliers are mainly distributed in surrounding locations of hot spots, and H-L outliers are continuously scattered near these cold spots (Figure 3). On the other hand, there is gradually strong positive autocorrelation, which is distinctly illustrated by increasing locations of hot spots and cold spots. Whether in Beijing or in Shanghai, ranges of the two area-connecting spots are enlarged gradually, and distributed in their central urbanized regions and outer suburbs respectively. Generally, the core-peripheral pattern with central hot spots and peripheral cold spots is highly related to urban land uses intensity. The spatial dispersion of Zip-code areas is clustered in central urban areas associated with densely-urbanized land uses as well as outer suburbs with lowest-density populations, suggesting underlying spatial processes referring to land uses intensity are promoting clustering.



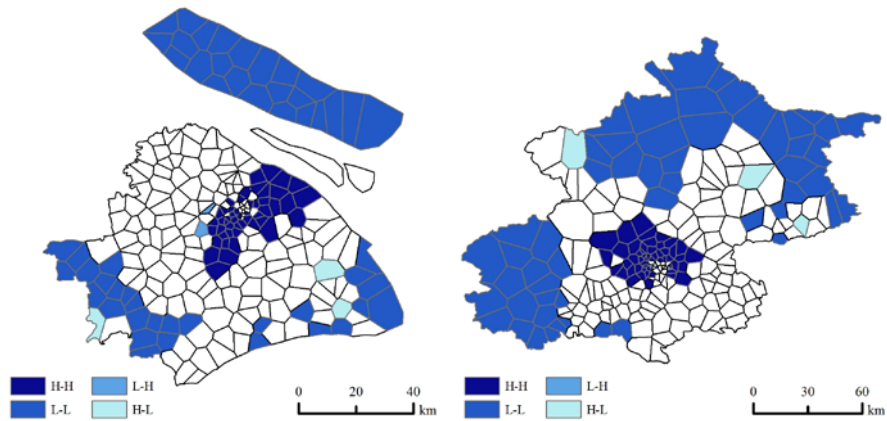
(a) 1991–1995



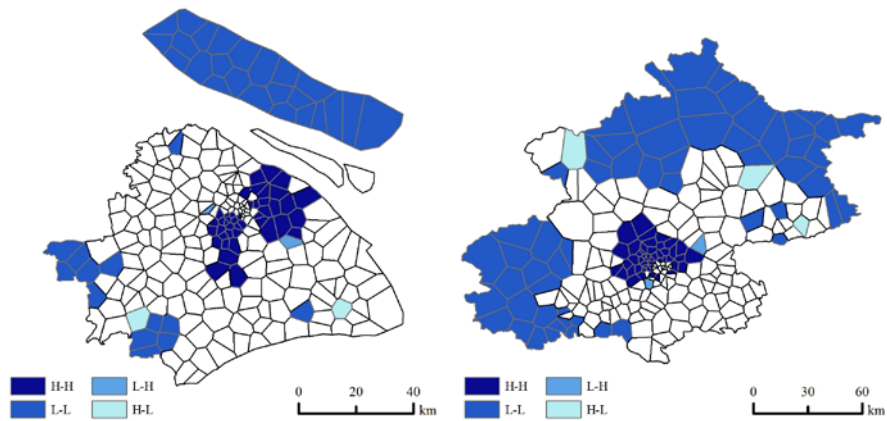
(b) 1996–2000



(c) 2001–2005



(d) 2006–2010



(e) 2011–2014

Figure 3 Bivariate LISA cluster map of innovation outputs in Shanghai and Beijing from 1991 to 2014

Note: on the left is Shanghai, and on the right is Beijing

4.2 Spatial clusters of Shanghai's innovation outputs

From 1991 to 2014, the distribution of Shanghai's innovation outputs is significantly positive spatial autocorrelation than random. Under the shifting of innovation resources from the center of Shanghai toward the east and south (i.e. Pudong new district, Minhang and Songjiang colleges towns), the spatial pattern of its innovation hot spots also was fragmented into the two subgroups with a dual-core structure (Figure 3), one includes Hongqiao community, Xujiahui community, Xinzhuang community and Zizhu Hi-tech Park, and the other is composed of Zhangjiang Hi-tech Park, Jinqiao Export Processing Zone, Wujiaochang community and Waigaoqiao community. However, the center urbanized regions within the Inner-ring expressway has gradually degraded from H-H clustering outliers to the locations with no significant autocorrelation. Meanwhile, the growth of L-L clusters shows continuously place-dependent, and basically distributed in the outer suburbs, such as Chongming Island, Qingpu district, Jinshan district as well as former Nanhui county of Pudong new district. Specifically, Chongming Island was full of L-L clustering locations from 2005 to the present. Although the number of L-L locations in Qingpu District and Jinshan District is decreasing gradually, their spatial distribution of the type aggregated more intensively than before. Differing from their constant concentration, the distribution of L-L locations in Nanhui District is mutative between dispersion and centralization. In the third and fifth stage, a small amount of L-L locations was observed in a scattered or dispersed pointal pattern. However,

in the second and fourth stage, there was a large increment of L-L locations, showing a uninterrupted areal distribution.

In contrast to aggregating areal distributions of positive autocorrelation types, the distribution of negative locations (e.g. L-H type and H-L type) are more extensively influenced by the suburbanization of innovation resources, which results in exhibiting a pointal disfusion or fragmentation. Both of the two types are distributed in the loactions surrounding the positive-type outliters such as hot spots and cold spots.

4.3 Spatial clusters of Beijing's innovation outputs

Compared with the suburbanization of innovation resources in Shanghai, the shifting or distribution of Beijing's innovation resources is significantly polarized during the past 25 years. As a result, larger amount of L-L outliers was uninterruptedly emerging in its outer suburbs, and H-H outliers are centralized in the inner urbanized areas, which shows the core-peripheral landscape with the aggregating hub encircled by the peripheral rural areas (Figure 3). Clearly, in absence of imcreasing number of positive autocorrelation locations, their distribution has been aggregated from initial relative dispersion to finally enlarging H-H cluster in the central Beijing, showing a strongly spatial cohesion and internal spillover. Although two main L-L cluters are located in the outer suburbs (such as Huairou, Miyun, Fangshan districts), their ranges are still enlarged and extending to the inner urbanized areas after 2000. Similar to Shanghai, in terms of the negative autocorrelation types such as L-H outliers and H-L outliers, not only does their size decrease, but also their locations have been pushed out of the downtown.

5 Conclusions and discussions

5.1 Conclusions

In this article, a Zip-code area scale provides a new insight into mapping spatial evolution of urban innovation outputs, which is meaningful to address some problems associated with spatial scale, administrative boundary and data processing. The geographical evolution of innovation outputs represented by scientific papers and patents was examined here in two cities of China using various ways, spatial pattern and autocorrelation analysis, similarities and deferences analysis.

Statistically, in terms of decreasing $V-C$ and $G-C$ values, their inequalities of Zip-code-scale innovation outputs in the megacities—Shanghai and Beijing were reduced continuously from 1991 to 2014, which indicates the slightly dispersive trend. While, increasing R and $S-D$ told a story that the two cities present a distinct polarization with the emergence of extreme-level outputs.

In spatial patterns, some similarities and differencnes were observed in the two cities. Specifically, a core-peripheral structure of innovation outputs was identified in the both cities. Almost of Zip-code areas with largest-or-larger innovation outputs were concentrated in their urbanized areas, especially in densely-populated built-up regions. Majority of lower-output areas were distributed in their suburbs, in particular the outer suburbs. Meanwhile, whether Shanghai or Beijing, the distributions of their innovation outputs were place-dependent and spatially innetial. Moreover, more extensive disparities between them were shown, due to differential distribution of their innovation resources. In Shanghai, because of the suburbanization of innovation resources such as universities and institutions, the pattern of urban innovation outputs was evolving from monocentric distribution to polycenters with multi-axis expansion and showed a shifting trend to

its east and south (e.g. Zhangjiang high-tech park, Minghan and Songjiang university towns). Evidently Differing from Shanghai, Beijing, was monocentric under continuous polarization. The distribution of its innovation outputs was locked in the core-periphery structure led by the downtown in the past 25 years, and exhibited the landscape with the higher-output hub encircled by the peripheral lower-output suburbs.

Based on the spatial autocorrelation analysis, spatial autocorrelation and aggregation of innovation outputs were evidently portrayed. The global Moran's I ($M-I$) for Zip-code areas were rather great and increasing gradually. The results indicated that the two 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 output described by LISA, the spatial distribution of each types basically tends to flock together.

5.2 Discussions

Although the spatiotemporal patterns of urban innovation outputs can be realized by city Zip code areas 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 innovative output, which limits the focus of this paper to studying the development of urban innovation spatial structure from the perspective of innovation outputs. The urban innovation system is a giant and complex system. Although the spatial evolution pattern of urban innovation 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 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 patent 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 Stanford University at the Sino-US Startup & Entrepreneur China Media Annual Conference 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.

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