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Research Article

Spatiotemporal Heterogeneity and Driving Force Analysis of Innovation Output in the Yangtze River Economic Zone: The Perspective of Innovation Ecosystem

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The Yangtze River Economic Zone (YREZ) is a major corridor of national science and innovation culture, an innovation-driven region that fosters new drivers of growth and leads transformation and development, and plays an important strategic support and exemplary leading role in the overall pattern of regional development. This paper analyzes the spatiotemporal differentiation characteristics of innovation output of 110 cities of YREZ from 2008 to 2018 by using Gini coefficient, coefficient of variation (CV), geographical weighted regression, and other methods. The factors affecting innovation output are selected from the perspective of innovation ecosystem. The results show the following. (1) Innovation output showed an increasing trend, and the high-value concentration cities in downstream areas gradually became prominent, the geographical concentration degree fluctuated and declined, and the distribution of innovation output gradually became balanced. (2) The global Moran's I index of innovation output shows a fluctuation pattern of "M" shape and an overall upward trend. The analysis of local spatial correlation indicates that spatial distribution pattern of innovation output has not changed significantly. (3) There is obvious regional heterogeneity under different impacts of factors of innovation ecosystem on innovation output. Enterprises have the greatest impact, followed by financial resources and infrastructure environment.

1. Introduction

As a key "booster" of regional development in the era of knowledge economy [1], innovation is an essential driving force to promote regional economic growth and enhance competitiveness [2, 3], and innovation output can reflect the ability and level of regional innovation [4]. The concept of innovation was first put forward by the economist Schumpeter [5], and its connotation and research field have been constantly updated [6]. The research of innovation paradigm has gone through three stages: linear innovation model, innovation system, and innovation ecosystem. The linear innovation theory advocates independent innovation within the enterprise, but it is difficult to adapt to the rapidly changing technological development, while the innovation system based on system theory advocates open innovation and puts forward the three-spiral theory of "politics, industry, and science" and the open innovation theory. Freeman studied the technology policy and economic performance of Japan in the 1980s and first proposed the concept of national innovation system. After the 1990s, Japan suffered an economic downturn, while Silicon Valley in the United States showed continued innovation vitality. "The Silicon Valley Edge: a habitat for innovation and entrepreneurship" proposes to understand the innovation ecosystem from an ecological perspective, arguing that the advantage of Silicon Valley lies in its dynamic, open, and powerful knowledge ecosystem. The success of Silicon Valley in the United States is largely due to the formation of a collaborative and interactive network innovation model of multiple subjects with universities, research institutions, and enterprises as the core elements and auxiliary elements such as governments, financial institutions, and intermediary organizations. In-depth cooperation and resource integration among technological innovation subjects produce continuous innovation. [7]. At the same time, Japan also put forward that the industrial structure policy should shift from technology policy to innovation policy based on ecological concept, emphasizing that the innovation ecology should be the foundation for Japan to maintain its sustainable innovation ability in the future. At present, innovation ecosystem is widely valued and studied in China, India, and other countries.

The YREZ stretches across the eastern, central, and western regions of China, and its population size and economic aggregate exceed the "half of the country" of the country. It is one of the regions with the greatest strategic support in China. Due to the great differences in economic development, natural resources, and industrial base among cities, the YREZ is generally divided into the upper, middle, and lower reaches. Among them, the upper reaches are Guizhou, Yunnan, Sichuan, and Chongqing, the middle reaches are Hunan, Hubei, and Jiangxi, and the lower reaches are Anhui, Zhejiang, Jiangsu, and Shanghai. On November 14, 2020, Xi Jinping hosted a symposium on comprehensively promoting the development of the YREZ in Nanjing, Jiangsu Province, and emphasized that the high-quality development of the YREZ will be promoted, a new model for coordinated regional development will be created, and new advantages in innovation-driven development will be created to enable the YREZ that has become the main force leading the domestic and international dual-circulation aorta and leading the high-quality economic development. There are six independent innovation demonstration zones in the YREZ, namely, Wuhan East Lake, Shanghai Zhangjiang, Southern Jiangsu, Changzhutan, Chengdu High-Tech Zone, and Hangzhou High-Tech Zone, and Shanghai and Hefei have been approved as comprehensive national science centers successively. All these will help to build the YREZ into a "science and innovation corridor."

As a major national development strategy, YREZ is the leading region of China's innovation-driven development [8]. The report on innovation and development of YREZ (2018) pointed out that the provinces and cities of YREZ have different levels of innovation investment, innovation capacity, and innovation development. From the perspective of innovative enterprises and innovative output, Jiangsu has the most, while Guizhou and Yunnan have the least, and 77.43% of the product exports of innovative industrial clusters are concentrated in downstream cities. The number of R&D personnel and patent authorization quantity shows that Jiangsu and Zhejiang accounted for 47.3% of YREZ, while Jiangxi, Yunnan, and Guizhou only accounted for 7.43%, with relatively low patent authorization quantity. At present, problems such as unbalanced distribution of innovation elements, large gap of innovation capacity, and segmentation of innovation market in the region seriously hinder YREZ from becoming an innovation-driven and high-quality representative in China.

Innovation ecosystem is an open and complex system of symbiosis, competition, and dynamic evolution between various innovation subjects and innovation environment through the connection and conduction of material flow, energy flow, and information flow. Its fundamental goal is to realize the continuous emergence of innovation. Therefore, it is necessary to scientifically measure the innovation output of YREZ and reveal its spatial evolution rules. By using the economic geography model, the driving factors of regional innovation output differences are analyzed from the perspective of the innovation ecosystem. It is conducive to narrowing the gap in regional innovation and development, enhancing the capacity and level of regional innovation, enhancing the spatial allocation effect of innovation, and promoting the coordinated development and high-quality economic development of YREZ. Based on this, this paper takes the period from 2008 to 2018 as the research period, with 110 cities of YREZ as the research objects. Taking the amount of patent authorization as the index of innovation output, using Gini coefficient, coefficient of variation (CV), and exploratory spatial data analysis (ESDA) method, this paper analyzes spatio-temporal heterogeneity of innovation output in YREZ. The factors affecting innovation output were selected from the key elements of building an innovation ecosystem and analyzed by using the geographical weighted regression model so as to provide reference for the promotion of the innovation output of YREZ.

2. Literature Review

Innovation is seen as key to enhancing competitive advantage in a constantly changing environment [9, 10]. With the development of innovation theory, the research of innovation has experienced linear model of innovation, innovation system model, and innovation ecosystem model [11]. The President's Council of Advisors on Science and Technology (PCAST) argues that the U.S. economic boom and its leadership are largely due to the innovation ecosystem [12]. Japan also emphasizes that innovation is the foundation for sustaining innovative capacity [13]. YREZ has rich innovation resources and is an important source of driving force for China's innovation. Therefore, the key step is to find the innovation impetus from the perspective of innovation ecosystem.

2.1. Research on Innovation Output. Innovation output is an important embodiment of regional innovation level. At present, there is no unified standard for its measurement in academia [14]. The measurement index mainly includes number of papers published [15], output value of new products [16], and number of patent applications [17]. Many scholars began to study regional innovation from a spatial perspective in recent years, using indicators such as Moran Index and Gini coefficient to measure the characteristics of innovation agglomeration and differentiation and using spatial measurement methods to study the influencing factors based on geographical proximity [18–20].

2.2. Research on Influencing Factors of Innovation Output. There are two main parts in analysis of factors affecting the innovation output: the internal factors of the innovation subject [21–23] and the macro environment and policy [24–27]. To be specific, the ability of innovation subjects to absorb innovation resources [28], market-oriented R&D activities [29], breadth and depth of cooperation [30], and efficiency of researchers [31] have positive effects on innovation output. However, there is no evidence showing that increasing the size of weak firms [32] or subsidies for R&D investment [33] will boost innovation output. In addition, the effect of innovation environment on innovation output, such as regional knowledge environment [34], legal environment [35], and technological environment [36], should not be ignored. At the same time, there is no denying that the system and governance of the government strongly support the innovation output [37, 38] and even have a long-term impact [39]. However, some studies have reached the opposite view, believing that environmental regulations [40] and state control over enterprises [41] will hinder innovation output.

2.3. The Role of the Innovation Ecosystem. The innovation ecosystem is an extension of the traditional innovation cluster network and a product of the combination of ecological theory and innovation research [42–44]. At present, the academic community has not reached a consensus on the definition of its connotation [45, 46], but most of them focus on the interaction between the internal elements of the innovation ecosystem and the basic characteristics of the interaction between the innovation system itself and the external environment [47–49]. In recent years, most countries, regions, and industries have realized that the innovation ecosystem is an important foundation for promoting sustainable innovation and have begun to examine their own state of innovation from perspective of innovation ecosystem and seek ways to improve their innovation capacity [50–52]. Studies have proved that the cooperation among diverse innovation subjects [53–55] and coordination and integration of heterogeneous innovation resources in the innovation ecosystem can help to improve the innovation rate and success rate [56]. The appropriate innovation environment can guide the direction of innovation and provide guarantee for innovation activities [57]. The openness of the innovation ecosystem not only promotes the flow of innovative elements such as material, information, and knowledge but also facilitates the commercialization of technologies, products, and other innovative achievements [58, 59].

2.4. Summary: Contributions of This Paper. In general, the research on innovation output and its influencing factors and innovation ecosystem is relatively mature, which lays a solid theoretical foundation for this paper. Existing studies have gradually begun to pay attention to the spatial heterogeneity of innovation output, extensively explored the root causes of innovation differences, and realized the important role of innovation ecosystem in improving innovation capacity. However, few studies have explored the reasons for the spatial heterogeneity in innovation output from the perspective of innovation ecosystem. Compared with existing literatures, the innovations of this paper are as follows. (1) Research perspective: in recent years, a growing number of scholars have begun to understand and study the development of urban agglomeration in China [60]. YREZ is rich in innovation resources, with one-third of the national universities and research institutions concentrated in Wuhan East Lake, Shanghai Zhangjiang, and other national independent innovation demonstration zones. It is the main battlefield of China's innovation-driven development. Therefore, it is of practical significance to find the reasons for the heterogeneity of innovation output regions in YREZ from the key components of the innovation ecosystem. (2) Research methods: first, the CV, Gini coefficient, and global Moran's I are used to measure the overall characteristics of innovation output of YREZ, and LISA cluster graph was presented. Second, the GWR model was constructed to seek ways to improve the innovation output.

3. Research Methods, Data Sources, and Index Selection

3.1. Research Methods

3.1.1. Coefficient of Variation (CV). CV is the ratio between the standard deviation and the mean of the selected samples, which can reflect the relative equilibrium degree of innovation. The formula is

$$\mathrm{CV} = \frac{\sqrt{\sum_{i=1}^{n}\left(\left(y_i - \overline{y}\right)/n\right)}}{y}, \quad (1)$$

where y_i is the i-th regional innovation output; $\overline{y}$ is the average value of innovation output in the city; and n is the number of cities. The larger the CV is, the more discrete the innovation output in the city is.

3.1.2. Gini Coefficient. Gini coefficient can reflect the degree of regional differences in development and measure the spatial agglomeration of innovation output in YREZ. The calculation formula is

$$G = \frac{1}{2n^2\overline{x}} \sum_{i=1}^{n} \sum_{j=1}^{n} \left|x_i - x_j\right|, \quad (2)$$

where G is the Gini coefficient, $\overline{x}$ represents the mean value of innovation output, and x_i and x_j represent innovation output of cities i and j, respectively. The value of G ranges from 0 to 1. The greater the Gini coefficient is, the greater the regional innovation output difference is and the higher the geographical agglomeration degree of innovation output is.

3.1.3. Exploratory Spatial Data Analysis (ESDA). ESDA is a common method to study the distribution characteristics of spatial data. It determines the regional adjacency relationship based on spatial weight matrix and reflects spatial dependence or heterogeneity of geographical phenomena through the distribution characteristics of spatial data.

(1) Global spatial autocorrelation: global spatial autocorrelation explores the overall spatial correlation and difference of innovation output in the region. Moran's I index is selected to measure the spatial correlation characteristics of innovation output in YREZ, and its spatial agglomeration trend is analyzed. The calculation formula is

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\left(x_i - \overline{x}\right)\left(x_j - \overline{x}\right)}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}}, \tag{3}$$

where I is global Moran's I, $\overline{x}$ is $(1/n)\sum_{i=1}^{n} x_i$, x_i and x_j represent the innovative output in region i and region j, respectively, and w_{ij} is the spatial weight matrix. The value of Moran's I is usually between (−1, 1), and a value greater than 0 indicates a positive correlation. In other words, regions with similar innovation outputs are in a state of spatial aggregation. Less than 0 means negative correlation, that is, areas with similar innovation outputs are distributed in a decentralized manner.

(2) Local spatial autocorrelation: local spatial autocorrelation is used to measure the degree and significance of regional spatial difference of innovation output in YREZ. Local spatial autocorrelation statistics refer to local Moran's I. Generally, the rule of local spatial distribution is analyzed in combination with Moran scatter plot and LISA aggregation graph. Its formula is

$$I_i = z_i \sum_{j\neq i}^{n} w_{ij} z_j, \tag{4}$$

where z_i and z_j are the standardized values of innovation output in regions i and j and w_{ij} is the spatial weight matrix. Under a given significance level, positive Moran's I shows that there are similar values in a region and its adjacent area. Similar values mean the spatial agglomeration effect exists (HH: high-value cluster areas and LL: low-value cluster areas); otherwise, there are spatial outliers (HL: high-low isolated area and LH: low-high hollow area).

3.1.4. Geographically Weighted Regression. GWR is an estimation method of spatial changing coefficient, which is used to test the regression relationship among spatial variables. Local parameter estimation is used instead of global parameter estimation to better evaluate the nonstationary state of spatial data, which is conducive to the exploration of spatial variation characteristics and spatial rules. Therefore, the GWR model is used to study spatial heterogeneity of driving forces of innovation output in YREZ. The formula is as follows:

$$Y_i = \alpha_0\left(u_i, v_i\right) + \sum_{j=1}^{k} \alpha_j\left(u_i, v_i\right) x_{ij} + \varepsilon_i, \tag{5}$$

where Y_i is the global dependent variable, x_{ij} is the independent variable, $\alpha_0(u_i, v_i)$ is constant, (u_i, v_i) represents the spatial coordinates of the i-th region, $\alpha_j(u_i, v_i)$ is the variable parameter of the j-th explanatory variable x_{ij} in the i-th region, and ε_i is a random error term.

3.2. Indicator Selection and Data Sources

3.2.1. Index of Innovation Output. Due to the large span of YREZ and because the regional innovation and development levels are different and the technical market turnover statistics and accounting methods are different, new product certification standards are also different. Although different regions have differences in patent inclination and patent quality, patent data are an embodiment of innovation activities. Therefore, this article makes use of patent data. However, regarding the choice of patent applications or authorizations, some scholars support the number of patent applications [61], mainly considering that the time lag of patent authorization is likely to cause information distortion. Scholars who support the amount of patent authorization believe that most inventors apply for patents out of strategic motivation, rather than for the purpose of obtaining patent authorization [62]. In view of the availability, scientificity, and representativeness of the data, patent authorization is selected to measure YREZ's innovative output.

3.2.2. Index Construction of Innovation Ecosystem. According to the discussion on innovation ecosystem in the literature review, this paper constructs an innovation ecosystem composed of innovation subjects, resources, and environment (Table 1). From the perspective of innovation subjects, universities, research institutions, and enterprises are the "engines" of innovation activities [63]. Among them, universities and research institutions are the core subjects of knowledge innovation. Their strong academic atmosphere has accelerated the burst of new ideas and new understanding and promoted knowledge innovation. They mainly focus on basic research [64, 65]. Because of its own profitability, enterprises are more focused on the characteristics of applied research and promote the output of products and services through application development [66, 67]. Therefore, the number of undergraduate universities and scientific research institutions is selected as the index to measure the universities and research institutes. The number of industrial enterprises above designated size is selected as the index to measure enterprise.

From the perspective of innovation resources, human resources are an important part of the innovation ecosystem and a decisive force affecting the innovation output [68]. Researchers are the key talents of innovation, and higher education teachers are not only the contributors of innovation output but also the disseminators of innovative ideas.

Table 1: Index construction of innovation ecosystem.

First class indicator	Second class indicator	Third class indicator	Fourth class indicator	Specific indicators	Unit
Innovation ecosystem	Innovative subject	Knowledge creator	Colleges and universities	Number of undergraduate schools in general institutions of higher learning	PCS
			Scientific research institutions	Number of scientific research institutions	PCS
		Knowledge applicator	Enterprise	Number of industrial enterprises above designated size	PCS
	Innovation resources	Human resources	Researcher input	R&D personnel per 10,000 people	People
			Investment in education personnel	Number of full-time teachers in colleges and universities	People
		Financial resources	Government expenditure on science and technology	The proportion of science and technology in public expenditure	%
			Research input	Internal expenditure of R&D funds	1000 CNY
	Innovation environment	Infrastructure environment	Informationization degree	Number of Internet broadband access ports	10,000 households
			Traffic environment	The road network density = highway mileage/total area of regional mileage	km/km^2
		Economic environment	The level of demand	Per capita retail sales of consumer goods	CNY
			Economic level	Per capital GDP	CNY
		Cultural and educational environment	Educational environment	Number of students in colleges and universities per 10,000	People
			Cultural environment	The total number of books in the public library	1000 volumes

Therefore, the human resources index is measured by a number of R&D personnel and full-time teachers in universities and colleges per 10,000 people. Financial resources are the guarantee of regional sustainable innovation [69, 70]. Enterprise R&D expenditure can stimulate enterprise innovation vitality, while government expenditure on science and technology plays a leading role in the investment of social capital in innovation activities. Therefore, the proportion of science and technology expenditure in public financial expenditure and the internal expenditure of R&D expenditure in each region are selected to measure the financial resource index.

From the perspective of innovation environment, infrastructure environment is an important carrier of the flow of innovation elements. In addition to the connectivity of traditional transportation infrastructure, the improvement of urban informatization infrastructure can increase the output of innovation [71, 72]. Therefore, the road network density and the number of Internet broadband access ports are selected to measure the infrastructure environment index of each city [73]. The level of economic development shows the attractiveness of a region to innovation factors, and the improvement of market environment will stimulate the innovation vitality of enterprises, thus enhancing the regional innovation output. Therefore, the economic environment index is mainly measured from the per capita GDP and per capita retail sales of consumer goods that affect innovation output. The regional cultural environment and educational environment are fertile soil for breeding innovative knowledge and talents and provide continuous nutrition for sustainable development of the innovation ecosystem [74, 75]. Therefore, the cultural and educational environment index is calculated by the number of students in colleges and universities and the total number of books in public libraries.

In this paper, the entropy method is used to calculate the weight of regional innovation ecological index, and the weight is used to calculate the third-layer index coefficient of each region, such as human resources, financial resources, infrastructure environment, and so on. Considering that innovation has a certain time lag from input to output, a 1-year lag period is adopted in this paper [76], that is, a dynamic panel regression model is constructed based on indicators of innovation ecosystem in 2017 and innovation output in 2018. The data are from *China urban statistical yearbook* from 2009 to 2019, *statistical yearbook* of all provinces in YREZ, *science and technology yearbook*, and *bulletin on national economic and social development* of each city.

4. Spatial Differentiation of Innovation Output

4.1. Overall Characteristics of Innovation Output Differences. According to the patent authorizations of prefecture-level cities in YREZ in 2008, 2013, and 2018, referring to classification criteria for innovation output and combining with the number of patent licenses in the YREZ [77], it is divided into four intervals of 0–5000, 5001–10000, 10001–20000, and more than 20001. The spatial agglomeration diagram of the innovative output of YREZ is drawn with ArcGIS10.2 software, and the evolution process of its spatial agglomeration is shown in Figure 1. The only city that exceeded

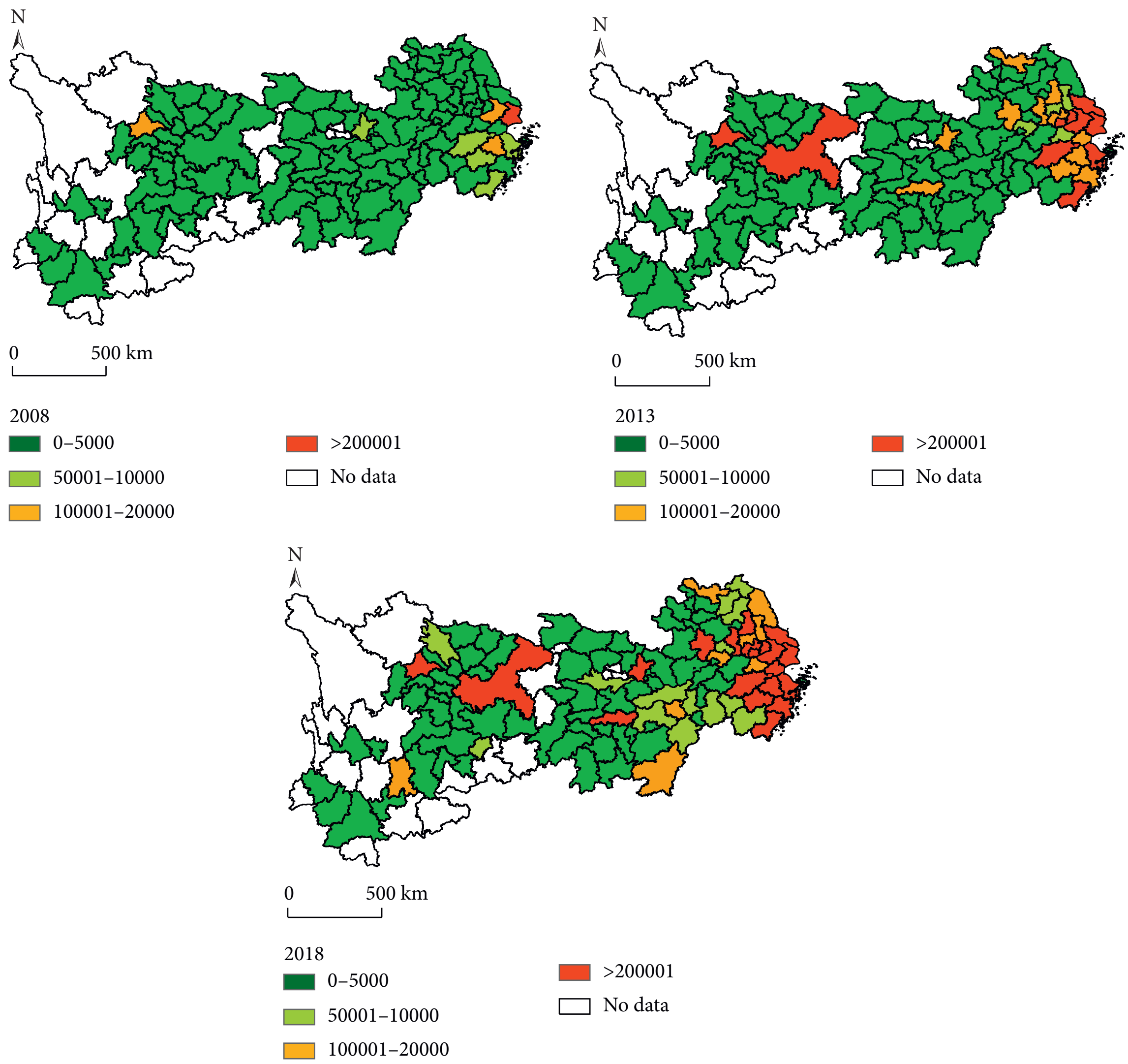


Figure 1: Spatial agglomeration of innovation output in YREZ in 2008, 2013, and 2018.

20,000 patents in 2008 was Shanghai. By 2018, it had increased to 19 cities, accounting for 17.27%, mostly concentrated in the coastal areas downstream of YREZ. In 2008, 101 cities with patent authorizations are below 5,000. The number fell to 86 cities by 2013 and to 68 in 2018, with the proportion falling from 91.82% to 61.82%, mainly distributed in midstream and upstream of YREZ. In general, evolution of the spatial and temporal pattern of innovation output has the following characteristics in YREZ: (1) The overall number of patent authorizations continues to increase, showing a gradual improvement; (2) The amount of patents granted in the coastal areas of the lower reaches of the YREZ shows a high-value concentration and continues to spread inland.

The article calculates the CV and Gini coefficient of urban patent authorizations from 2008 to 2018 in Figure 2 so as to show the spatial difference of urban innovation output in YREZ. The CV and the Gini coefficient showed a trend of decrease from 2008 (2.3637 and 0.5707) to 2018 (1.6179 and 0.3404), while the former has a slight fluctuation. It shows that the urban innovation output of YREZ becomes more and more balanced, and the geographical concentration gradually decreases, showing a trend of convergence.

In order to highlight the neighboring areas of spatial relationships, we use GeoDa software construction space adjacency matrix to calculate Moran's I index value of innovation output in YREZ during 2008–2018 (see Figure 3). As can be seen from Figure 3, Moran's I index is greater than 0 from 2008 to 2018 and shows a rising trend. This shows that a positive spatial correlation exists among innovation output in the various regions of YREZ, showing a significant spatial agglomeration phenomenon, and the overall trend is rising with some fluctuations. In detail, the first trend of fluctuation of Moran's I index is in 2008–2010, which jumped from 0.3996 to 0.5366, with an average annual growth rate of 15.88%, reflecting that spatial agglomeration of innovation output in YREZ is increasing in this stage. Then, the value fell to 0.4681 in 2013, reflecting a gradually weakening spatial agglomeration. The second trend of fluctuations of Moran's I index is in 2013–2018, eventually converging to 0.4316, with

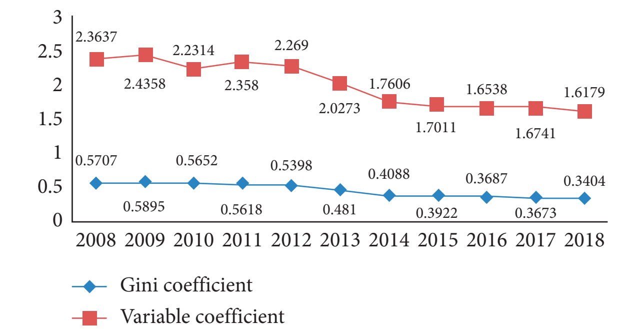


FIGURE 2: Differences and dynamic changes in innovation output of YREZ from 2008 to 2018.

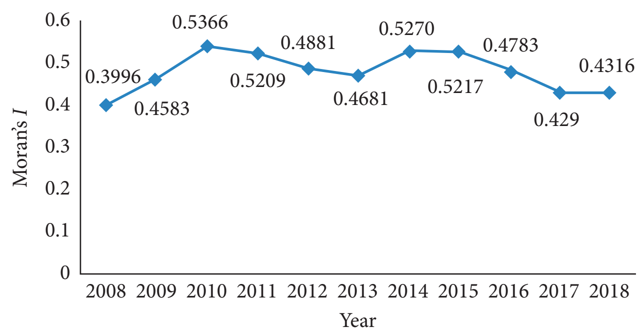


FIGURE 3: The evolution of Moran's I index from 2008 to 2018.

an average growth of 8% compared with 2008, suggesting that innovation output fluctuates and rises. It generally presents an "M" shaped wave pattern.

4.2. Local Autocorrelation Analysis of Innovation Output. Moran's I index of global spatial autocorrelation reveals the spatial dependence of YREZ during 2008–2018, while the local spatial autocorrelation LISA index reflects the correlation between the same attributes of each spatial position and the neighboring locations around them. Taking 2008, 2013, and 2018 as sample, GeoDa software was used to analyze the spatial correlation and cluster evolution of innovation output in YREZ, and LISA clustering results of innovation output are shown in Table 2.

Table 2 shows that spatial distribution pattern of innovation output in YREZ basically did not change significantly in 2008, 2013, and 2018, which indicates that innovation activities have certain spatial locking characteristics. Taizhou (Jiangsu), Nantong, Taizhou (Zhejiang), Suzhou, Shanghai, Huzhou, Jiaxing, and Shaoxing are always in high-value cluster areas (HH). The city's innovation output is high, and the average level of peripheral innovation output is also high, which reflects the obvious spatial agglomeration effect. This shows that the level of innovation output of this city and its surrounding cities is relatively stable. These cities are concentrated in the Yangtze River Delta region, which is one of the regions with the strongest innovation capacity in China. Innovation resources are shared in the region, and Shanghai, Suzhou, and other cities have a strong driving effect, which makes the innovation output level of these cities relatively high. Compared with 2013, the low-high hollow area (LH) increased in Xuancheng in 2018, indicating that the city's innovation output is lower than that of the surrounding cities. It reflects that the growth rate of innovation output in the surrounding area is higher than that of Xuancheng. Most relatively economically backward areas (Baoshan, Lincang, Panzhihua, Liupanshui, etc.) are distributed in low-value cluster areas (LL), and innovation output in those areas and surrounding areas is low. In 2013, the number of LL cities increased by half compared with that in 2008, and it was widely distributed in midstream and upstream of YREZ. By 2018, the number of LL cities was reduced, mainly concentrated in the upper reaches, which indicated that the innovation output in the middle reaches increased, and the LL in the upper reaches was enhanced. Chongqing has always been a high-low isolated area (HL) of innovation output. The city has a marked polarization characteristic, is at the center of polarization, and has a low diffusion effect on innovation output in the surrounding areas; by 2018, Kunming becomes HL from LL, indicating that Kunming's innovation output has increased compared with surrounding cities. Compared with the surrounding cities, Chongqing and Wuhan are both national central cities with good economic strength, development level, innovation level, and innovation environment. However, due to weak spillover effect on the surrounding areas, they appear as high-low isolated areas.

5. Analysis on the Influencing Factors of Innovation Output in YREZ

5.1. Result Analysis. During the calculation of the GWR model, the core type is ADAPTIVE and the bandwidth is AICc. The results show that R^2 is 0.9620 and adjusted R^2 is 0.9570, indicating that the GWR estimation model can better simulate the effects of innovation ecosystem variables on innovation output. By sorting out the regression coefficients in the calculation results, the five statistic values were selected. It can be seen from Table 3 that each variable of the innovation ecosystem has a specific regression coefficient on the impact of each city's innovation output with large differences in the values, which shows that the impact of each variable on different cities has a large difference. From the perspective of regression coefficients and average values, knowledge applicator has a positive impact on innovation output, followed by financial resources and basic environment; knowledge creator, human resources, economic environment, and culture and educational environment shows both positive and negative effects on innovation output. In addition to the economic environment, other influencing factors are mostly positive effects, and a few regions have negative effects.

5.2. Spatial Heterogeneity Analysis of Influencing Factors

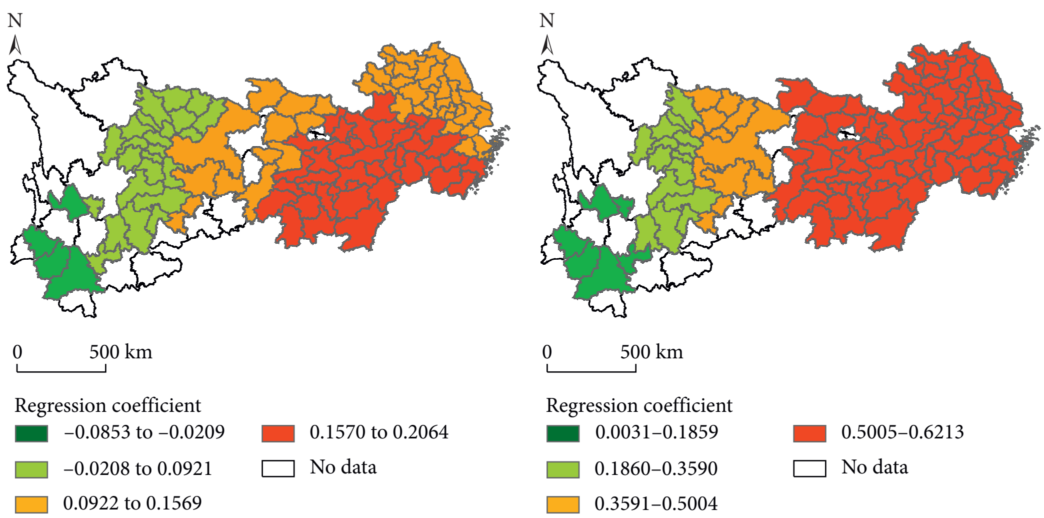
5.2.1. Innovation Subject. Innovation subjects have different effects on the innovation output of each city. Specifically, in Figure 4(a), the regression coefficient range of knowledge

Table 2: LISA clustering results of innovation output of YREZ based on the Moran scatterplot.

Quadrant	2008	2013	2018
Quadrant one (HH)	Huzhou, Jiaxing, Jinhua, Nantong, Ningbo, Shanghai, Shaoxing, Suzhou, Taizhou (Jiangsu), Taizhou (Zhejiang)	Taizhou (Jiangsu), Nantong, Taizhou (Zhejiang), Suzhou, Shanghai, Huzhou, Jiaxing, Shaoxing, Wuxi	Huzhou, Jiaxing, Jinhua, Nantong, Shanghai, Shaoxing, Suzhou, Taizhou (Jiangsu), Taizhou (Zhejiang), Wuxi, Zhenjiang,
Quadrant two (LH)	NA	Xuancheng	Xuancheng
Quadrant three (LL)	Jiujiang, Baoshan, Lincang, Panzhihua, Liupanshui, Kunming, Jingdezhen, Bengbu	Jiujiang, Baoshan, Lincang, Panzhihua, Liupanshui, Kunming, Bazhong, Zigong, Yibin, Pu'er, Ji'an, Huaihua, Nanchong, Bijie	Baoshan, Lincang, Panzhihua, Liupanshui, Bazhong, Zigong, Yibin, Pu'er
Quadrant four (HL)	Chongqing	Chongqing, Wuhan	Chongqing, Kunming

Table 3: Calculation results of the GWR model.

Influencing factor	Min	Lower quartile	Mean	Upper quartile	Max
Knowledge creator	−0.0853	0.0946	0.1284	0.1681	0.2064
Knowledge applicator	0.0031	0.4332	0.5107	0.6032	0.6213
Human resources	−0.0424	0.0131	0.1247	0.2273	0.7183
Financial resources	0.1917	0.2188	0.2581	0.2955	0.4182
Infrastructure environment	0.0252	0.0328	0.0380	0.0424	0.0544
Economic environment	−0.0512	−0.0398	−0.0201	−0.0024	0.0066
Culture and educational environment	−0.2156	0.0499	0.0770	0.1221	0.1281



(a) (b)

Figure 4: Spatial distribution of regression coefficient of innovation subject to innovation output. (a) Universities and research institutes. (b) Enterprise.

creator to innovation output is (−0.0853, 0.2064). The regression coefficients of all cities are positive except Baoshan, Lincang, Lijiang, and Pu'er. In other words, 96.36% of the cities' universities and research institutions positively affected innovation output, which shows that innovation sources of innovation ecosystem provide impetus for the realization of sustainable innovation output. Among them, Baoshan, Lincang, Lijiang, and Pu'er showed relatively weak negative influence, which may be due to the relatively weak economic foundation and scientific research atmosphere, leading to the failure of input into innovation output. Most cities in Hunan, Hubei, Jiangxi, Anhui, and Zhejiang are the most affected by universities and research institutions, while most cities in Sichuan and Yunnan are the least affected. This difference is mainly related to the following factors. On the one hand, the quantity and quality of universities and research institutions in different regions determine the efficiency and quality of innovation output. On the other hand, whether universities and research institutions can find their location in innovation ecosystem and establish cooperation mechanism with enterprise is the key to realize the transformation of innovation achievements. For example, the number of universities and scientific research institutions in Ya'an, Bazhong, Leshan, Guangyuan, Shaotong, and other cities is small, and the lack of high-level universities and research institutions leads to a weak impact on innovation output, while Shanghai, Hangzhou, Chongqing, Nanjing, Wuhan, and other places are the concentration of double first-rate universities, providing a large number of high-quality scientific research resources for regional innovation, while the region pays attention to deep integration of industry-university-research, which can accelerate the knowledge spillover and can avoid ignoring market demand.

Figure 4(b) shows the spatial distribution of enterprises. Enterprises, as the knowledge applicant, are the most important factor influencing innovation output and show positive correlation. Ganzhou (0.6213) has the largest regression coefficient, and Baoshan (0.0031) has the smallest. This shows that in the innovation ecosystem, enterprises, as the main body of innovation, are one of the important driving forces of regional innovation development. The regression coefficients of enterprise are distributed continuously in space. Most of the high value areas are concentrated in Jiangsu, Anhui, Zhejiang, Shanghai, Jiangxi, Hunan, and Hubei, with 78 cities in total. For every 1% increase in the number of enterprises in these cities, the innovation output will increase by 0.5005%–0.6213%. The regions where innovation output is relatively less affected by enterprises are mainly in Sichuan and Yunnan. The regression coefficients of these regions are between 0.0031 and 0.1859, which shows that enterprises in this region have not fully played the role of innovation. There are two possible reasons. First, the number of enterprises is small, which cannot gather innovation resources, resulting in the increase of innovation cost and risk, so the innovation output is low. Secondly, the construction of collaborative innovation platform of industry-university-research in this region is not perfect, and the ability of enterprises to absorb and transform new knowledge is weak, which causes the deficiency of technological innovation ability and the lack of dominant position in innovation system, thus affecting the innovation output.

5.2.2. Innovation Resources. Each index of innovation resources has different effects on urban innovation output. In detail, the regression coefficient of human resources to innovation output ranges from −0.0424 to 0.7183, as shown in Figure 5(a). Among them, the human resources of 16 cities such as Ganzhou, Fuzhou, Ji'an, Nanchang, and Pingxiang have negative effects on innovation output, and the remaining 85.45% have positive effects, which to a certain extent proves that human capital is the endogenous power of regional innovation output promotion. The gathering of scientific and technological talents helps to enhance regional knowledge absorption ability, break the knowledge barrier of technology diffusion, and enhance regional knowledge diffusion and regional innovation output. In particular, Baoshan, Lincang, Lijiang, Pu'er, Panzhihua, Ya'an, and other cities in the upper reaches of YREZ will increase innovation output by 0.4320%–0.7183% for each 1% increase in human resources in these areas. This is because compared with the downstream areas, the human resources in upstream are relatively scarce. According to the law of diminishing marginal utility, the innovation output brought by increasing the input of human resources is higher than that of other areas with relatively rich human resources. In addition, human resources in most cities of Jiangxi have a weak negative impact on innovation output, which may be due to the implementation of relevant documents, such as "Pilot measures for encouraging innovation and entrepreneurship of scientific and technological personnel in provincial independent scientific research institutes" and "Several provisions of Jiangxi Province to encourage scientific and technological personnel to innovate." This fully arouses the initiative of innovation subjects, provides support for transformation of scientific and technological achievements, and creates more innovative output with less human resources.

Financial resources are positively influencing and promoting the innovation output, the performance of which corresponds to Figure 5(b). The maximum value of regression coefficient is Pu'er (0.4182), and the minimum value is Zhoushan (0.1917). The coefficient decreases with "upstream-middle-downstream." This confirms that R&D investment and government science and technology expenditure are important driving forces to increase innovation output. The financial input of upstream cities has a greater positive effect on innovation output than that of downstream cities, especially Baoshan, Lincang, Lijiang, Pu'er, Panzhihua, Yuxi, Ya'an, Kunming, and Qujing. This may be due to the weak economic foundation, insufficient R&D investment in the upstream, and the fact that the region is in the initial stage of regional innovation and has not yet formed a relatively complete innovation network. Therefore, increasing financial input can speed up the construction of regional innovation network, optimize the innovation environment, and improve the innovation capacity and level. At the same time, it should be noted that although the financial input of these cities promoted the innovative output to a certain extent, the gap with the innovative output brought by the input of human resources was relatively large. The reasons may be as follows: the unreasonable intensity and structure of R&D investment leads to insufficient R&D investment in some regions and fields, while R&D investment in other regions and fields has a diminishing marginal effect. In addition, government expenditure on science and technology provides financial support for regional innovation entities, but it may also interfere too much in enterprise innovation, resulting in inefficient resource allocation and affecting innovation output.

5.2.3. Innovation Environment. The indicators of the innovation environment have different effects on urban innovation output. In Figure 6(a), the infrastructure environment has a positive effect, and the economic environment, culture, and education environment have both

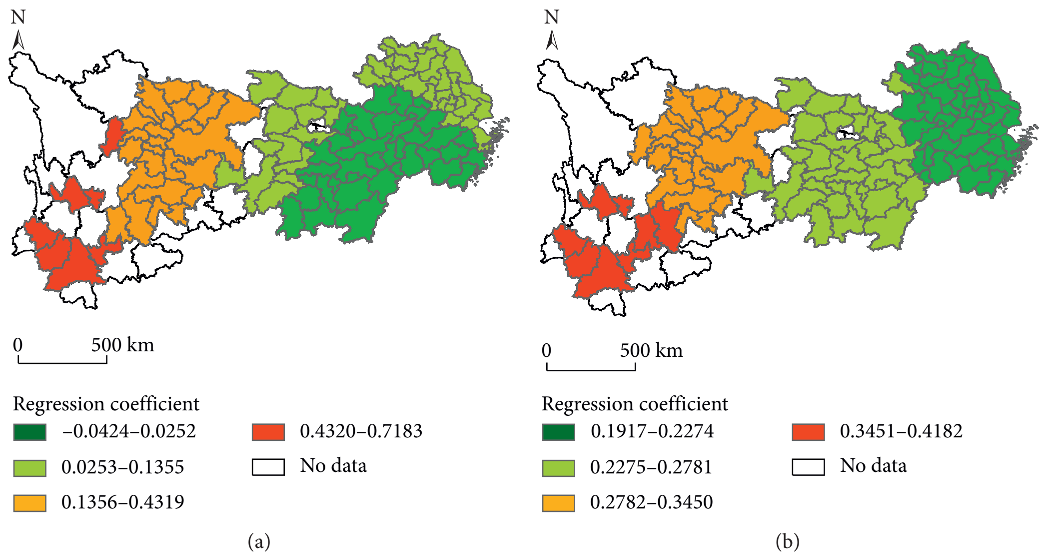


Figure 5: Spatial distribution of regression coefficients between innovation resources and innovation output. (a) Human resources. (b) Financial resources.

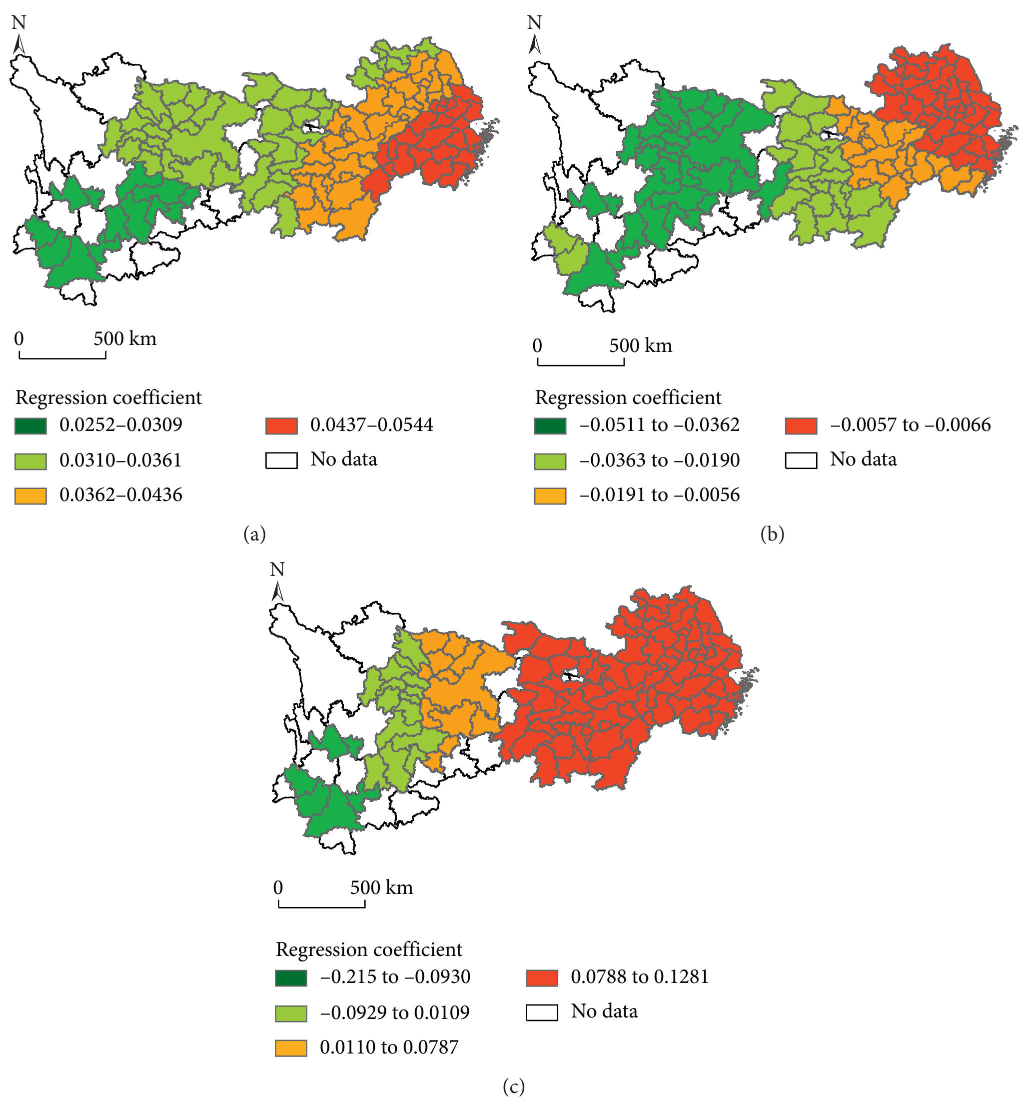


Figure 6: Spatial distribution of regression coefficient between innovation environment and innovation output. (a) Infrastructure environment. (b) Economic environment. (c) Cultural and educational environment.

positive and negative effects. In detail, the regression coefficients of the infrastructure environment on innovation output are all positive, and the range is 0.0252–0.0544. This may be because the improvement of the urban transportation infrastructure and the improvement of informatization can speed up the spread of technology and knowledge in the market, enhance interregional exchanges and cooperation, and facilitate the rational allocation of innovative resources, which will help increase the output of innovation. Specifically, the infrastructure environment in the upstream has the smallest impact on innovation output, and the impact level in the mid- and downstream exhibits a staircase pattern that increases from northwest to southeast. Traffic infrastructure is relatively backward in Pu'er, Yuxi, Lincang, Kunming, Qujing, and Baoshan due to the complex topography and poor geological conditions. Besides, the Internet penetration rate in those cities is below the national average level, which also hinders the flow of knowledge and information, leading to lower impact on innovation output. The regression coefficient in the Yangtze River Delta is relatively high. According to "*Digital China Construction Development Report (2018)*," informatization development evaluation index in Jiangsu, Shanghai, and Zhejiang ranks among the top five in the country. In recent years, it has continuously promoted the development of informatization innovation and strengthened the construction of new infrastructure, gradually building a regional network information technology innovation system to provide strong support for innovation and development.

In Figure 6(b), the regression coefficient of the economic environment on innovation output ranges from −0.0512 to 0.0066, of which 92 cities have negative impact, accounting for 83.64% of the total. With characteristics of "upstream-middle-downstream," the influence intensity gradually weakened. Among them, cities such as Liupanshui, Qujing, Anshun, Bijie, and Kunming have a strong hindrance to innovation output, while cities such as Hefei, Bengbu, Huzhou, Huaibei, and Shaoxing have relatively smaller hindrance. The attractiveness of a region to innovative resources is related to economic development, and the market is a platform for contact between innovation supply and innovation demand. Both have an undeniable role in enhancing innovation output. However, from the regression results, the economic environment has not actively promoted innovation output of each city and even shows a slight obstruction effect, which is contrary to theoretical cognition. There are two possible reasons: first, some cities are caught in the path-dependent predicament, which makes it impossible to carry out path innovation on the original industrial chain; second, the market environment's inadequate guarantee mechanism for innovation output has resulted in insufficient innovation motivation for innovation subjects but has reduced innovation output. However, there are also some cities represented by Shanghai, Suzhou, and Nanjing whose economic environment is more optimistic about innovation output. This may be due to the rapid growth of tertiary industry and better quality of economic development in those cities. At the same time, they pay attention to creating an ecological and livable urban environment, attracting high-tech industries and high-tech talents to settle in, creating a fair competition market environment for them, and promoting the transformation of innovation results.

In Figure 6(c), the coefficient of culture and education environment on innovation output ranges from −0.2156 to 0.1281. There are 94 cities showing positive influence, which proves to a certain extent that the ability of innovation is inseparable from the social culture and educational environment. Among them, cities such as Shanghai and Nanjing are the pioneering areas for reform and opening up. Cultural environment of encouraging innovation and tolerance for failure and high-quality educational resources provide more possibilities for innovation output. However, 14.55% of the cities in YREZ showed a negative correlation, mainly distributed in Baoshan, Lincang, Lijiang, Pu'er, Panzhihua, Yuxi, and Meishan. The reasons for the negative impact are as follows. First, the number of universities in the region is few, educational resources are scarce, the proportion of the population with higher education is low, coupled with the lagging economic development, and the brain drain is serious, resulting in low level of humanities education and innovation output. Second, it is important for the whole society to actively create an atmosphere that supports and encourages innovation. However, the innovation foundation in these regions is relatively weak, and a complete innovation system has not yet been formed. It shows that even a better cultural and educational environment cannot promptly increase innovation output.

6. Conclusion and Suggestion

6.1. Conclusion. The Gini coefficient, CV, and exploratory spatial data are used to analyze the changes and spatial correlation and cluster evolution of 110 cities' innovation output in YREZ from 2008 to 2018, and then we use the entropy method to calculate innovation ecosystem index of each city. Finally, the impact of each factor of the innovation ecosystem on innovation output is analyzed by using the GWR model. Some conclusions can be drawn as follows. First, the overall level of urban innovation output in YREZ has increased year by year, and the geographic concentration has shown a downward trend in fluctuation. From 2008 to 2018, the number of patent authorizations showed increase year by year, and the downstream high-value agglomeration areas gradually became prominent. From CV and Gini coefficient, there is a trend of decreasing volatility, the geographical concentration gradually decreases, and the distribution of innovation output has evolved from an imbalance to a state of equilibrium.

Second, the innovation output of the cities in YREZ shows a positive spatial correlation. The agglomeration distribution of cities with similar innovation output shows an overall upward trend. Moran's I index of innovation output exhibited an "M" shaped volatility pattern during 2008–2018. Local spatial correlation analysis indicates that spatial distribution pattern of innovation output has not changed significantly. The HH area is concentrated in the downstream, and the LL area is concentrated in the upstream, reflecting the obvious spatial agglomeration effect.

Chongqing and Kunming are located in the HL area, showing obvious polarization characteristics, and Xuancheng's innovation output level is significantly lower than that of the surrounding cities, so it is located in the LH area.

Third, the influence of each factor of the innovation ecosystem on innovation output has obvious regional differences. Overall, knowledge applicators, financial resources, and infrastructure environment positively influence innovation output, and knowledge applicators have the greatest impact; knowledge creator, human resources, economic environment, and cultural and educational environments have both positive and negative effects on innovation output; in addition to the economic environment, other influencing factors are mostly positive effects, and a few regions have negative effects and significant heterogeneity. Among them, universities and research institutes, enterprise, and the cultural and educational environment's effect on innovation output have spatially exhibited the layout characteristics of "high in the west and low in the east". The intensity of human input, financial input, and economic environment's effect on innovation output in the spatial distribution generally shows the characteristics of "high in the east and low in the west"; the degree of impact of the infrastructure environment in the middle and lower reaches shows enhanced ladder from northwest to southeast.

6.2. Policy Recommendations. First, we should break the traditional boundary of innovation subject and realize multiparty cooperation and deep integration. We should break the boundary between knowledge creators and knowledge applicators in innovation ecosystem, strengthen the endogenous power of enterprises as main institutions, stimulate the synergy of universities and scientific research institutions to support innovation, maintain dynamic balance in competitive symbiosis, avoid the phenomenon of "innovation isolated island," and realize cross-border cooperation, multiparty cooperation, and deep integration among innovation subjects. The influence of innovation subjects on innovation output is weak in the upper reaches and strong in the middle and lower reaches. Therefore, the cultivation of innovation subjects in the upper reaches should be strengthened to fully stimulate innovation vitality. Specifically, for universities and research institutions, they should, according to their own advantages, establish innovation priorities in a differentiated way. At the same time, a coordination mechanism is formed between the various innovation entities in the system, so as to realize the effective complementation and connection of innovation resources and enhance the innovation output of the region. First of all, universities and research institutions should remove the administration of academic issues and avoid the link between administrative power and scientific research resources, which leads to the lack of autonomy of scientists. At the same time, they should establish a scientific and reasonable innovation incentive mechanism to maximize the innovation vitality of researchers. Secondly, under the unified layout and coordinated guidance of the government, we should make full use of funds for scientific research projects from various channels to increase the construction of infrastructure for scientific research institutions and support innovation of universities and research institutions in the fields of infrastructure and cutting-edge technology research. Finally, we should actively explore cooperation channels with enterprises, strengthen the positive interaction between universities, research institutions, and enterprises, set up market-oriented projects and carry out R&D, and open up a channel for patent transformation of scientific and technological achievements. For knowledge carriers, especially in upper reaches of YREZ, we should strengthen the enterprise as the main body of improving the innovation output. For knowledge users, especially the upper reaches of the Yangtze River Economic Belt, enterprises should strengthen their position as the mainstay of innovation output, guide various innovation elements to gather in enterprises, increase support for enterprise innovation, and introduce and support technological innovation. Leading enterprises play their leading role in demonstration, effectively attracting various innovative resources and elements, accelerating the improvement of the industrial chain and innovation chain, and driving the growth of a large number of small- and medium-sized enterprises, making them the backbone of improving technological innovation capabilities and increasing innovation output. Besides, the government should give full play to its "policy power" and introduce special policies to further increase subsidies and tax incentives for innovation-oriented enterprises so as to reduce their innovation costs.

Second, we should increase the investment of innovation resources reasonably and accelerate the development of scientific and technological innovation to improve quality. The influence of innovation resources is mostly positive, which is mainly manifested in the high east and low west. Therefore, the input of human resources and financial resources in the eastern region has greatly improved the innovation output of the region. Reasonable input of human and financial resources to innovation provides key support for innovation ecosystem construction and innovation output. For the human resources of innovation ecosystem, it is undeniable that human resources are the key force to enhance innovation output. First of all, deepen the reform of the education system, pay attention to basic research, and train "advanced" innovative talents. Secondly, it should give more autonomy to the researchers in scientific research institutions and universities and stimulate their creative talents and vitality to the greatest extent by giving them intellectual property rights and material incentives. Finally, by enhancing the "talent stickness" to enhance the "innovation concentration" and constantly optimizing the innovation ecological environment, we will create a "strong magnetic field" for talents to gather, which will be transformed from attracting investment to "attracting talents and attracting talents." We will focus on introducing leading talents in key technology fields and emerging technology fields to give full play to the siphon effect and realize "attracting talents with talents." In terms of financial resources, it is an effective way to improve innovation output to reasonably increase the investment in innovation financial resources and continuously improve the utilization efficiency of funds. On the one hand, we should encourage universities and research institutes to increase investment in R&D by establishing a diversified mechanism for government, enterprises, and financial institutions to invest in innovation and guide nongovernmental and private capital to invest in R&D so as to reduce the innovation risks of enterprises. On the other hand, each innovation subject should constantly improve the system and mechanism of science and technology fund management to maximize the utilization rate of funds. For example, we should reform the way the government funds for science and technology are used, eliminate the disadvantages of the traditional model of "project approval in advance and grant free funds," set up special funds, and make full use of the market mechanism to leverage financial capital to invest in the science and technology industry.

Third, continuously optimize the innovation environment and fully stimulate the enthusiasm of the main body of innovation. The innovation environment affects the creation, flow, and application capacity of innovation elements such as knowledge and technology. Optimizing the environment of the innovation ecosystem helps the innovation subjects to strengthen cooperation and exchange, effectively coordinate the use of innovation resources, and accelerate the flow of innovation elements. The impact of innovation environment on innovation output is complex, so it should be optimized according to the differences of innovation environment in different regions. For the infrastructure environment, improving the infrastructure environment, especially in terms of information infrastructure, is conducive to greatly increasing innovation output. Therefore, the investment in informatization should be increased, and the funds should be appropriately inclined to the communication engineering, especially in the areas with low informatization level in upstream of the Yangtze River, so as to actively promote the informatization infrastructure construction in YREZ and give full play to the innovation-driven effect of informatization. In addition, each innovation subject should be good at using information technology to build an open and shared scientific and technological information platform, build the "Internet +," integration of the Yangtze River Economic Belt, break through barriers that hinder the flow of knowledge and technology, and promote the flow of information and cooperation and exchanges between regions to achieve information exchange, resource sharing, and knowledge sharing which are used to improve innovation efficiency and narrow the regional innovation gap. For the economic environment, we should stand at the commanding height of future industrial development, target emerging industries such as cloud computing and artificial intelligence, and focus on fostering development so as to constantly improve the quality of economic development. In addition, for the purpose of stimulating innovation, improve the construction of the intellectual property management system, immediately promulgate laws and regulations, establish a benefit-sharing and risk-sharing benefit mechanism, form a joint force for system protection, and optimize the legal "soft environment" that promotes technological innovation. Efforts will be made to solve the problems faced by intellectual property protection, effectively guarantee the economic benefits of innovation entities, and achieve a win-win situation for multiple entities. For the cultural and educational environment, first, we should strengthen the publicity of science and technology, fully arouse the enthusiasm of various innovation subjects, create a scientific and technological innovation atmosphere, and form a culture and social values that are conducive to innovation, tolerate failure, encourage experimentation, and advocate competition. Second, education is the basis of the social and cultural environment. In particular, institutions of higher learning in upstream of the Yangtze River must grasp the social changes, enhance the quality of education and pay attention to the improvement of students' innovative consciousness and ability, and optimize the population structure.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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