Coordinated Development of Innovation System in China’s Yangtze River Economic Belt, a Demand and Supply Perspective

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Abstract: The Development of the Yangtze River Economic Belt (YREB) is not only a major regional coordination development strategy in China but also a core carrier supporting China’s innovation-driven development. Under this background, this paper explored the evolution, spatial difference, and coordination development of the regional innovation system in the period of 2007 to 2017 from the demand and supply perspective. We found that, during the study period, the development level of the innovation demand subsystem (IDS) and innovation supply subsystem (ISS), as well as their coordinated development, all showed an increasing trend. The development gap of IDS and the coordinated development among cities in YREB was quite balanced, while there existed a large gap among cities in YREB in the development of ISS. The development of IDS was better than the development of ISS in most of the cities of YREB, indicating that the innovation development of cities in YREB needs supply-side structural reform urgently. Most cities in YREB were at the moderately or slightly uncoordinated development phase, and Shanghai was the only city with coordinated development between IDS and ISS. This paper enriches the regional innovation system from a new perspective, the demand and supply perspective, as well as providing suggestions for the coordinated development of the regional innovation system in YREB.

Keywords: regional innovation system; innovation demand subsystem; innovation supply subsystem; regional coordination; Yangtze River Economic Belt

1. Introduction

The contribution and mechanism of innovation in national economic growth has constantly been revealed since the pioneering work of Schumpeter [1]. However, under the context of economic globalization, the flow of innovation resources gradually broke through the national boundaries, and many spatial agglomerations appeared. Meanwhile, the research framework of the national innovation system cannot fully explain the emergence of regional industrial clusters and regional innovation networks; therefore, the regional innovation system was proposed. In the process of developing from national innovation system to regional innovation system, innovation economics and innovation system research were combined with the study about regional science, spatial economics, and economic geography, and the importance of regional difference and local initiative in the evolution of innovation system was gradually been recognized. Many scholars have studied the regional innovation system from its components, structure, function, and determinants [2–4]. With regard to the evaluation of regional innovation system, many index systems mainly consisting of innovation environment, innovation actors, and innovation performance that measure development level of regional innovation system are constructed [5–7].

The co-evolution and co-development of the demand side and supply side is the key to sustainable and stable economic and social development [8]. Driven by the long terms of the demand-pull policy, China has experienced 40 years of rapid growth. However, under a
series of internal and external factors, such as the decline of China’s demographic dividend, the accumulation of middle-income trap risks, and the deep adjustment of international economic structure [9], the demand and supply relationship of China’s economic development is now facing a structural imbalance that cannot be ignored, and the mismatch between demand side and supply side has become the biggest factor holding back China’s sustained economic growth. Under such circumstances, the Strategy of Innovation-driven Development and Regional Coordinated Development are the two supporting strategies promoting the transformation and upgrading of economic structure [10], and further helping achieve a high quality of economic development in China’s New Normal, in which structural and quality economic development, rather than the economic aggregate growth, is emphasized. The Innovation-driven Development Strategy clarifies that technological innovation is the core power in supporting China’s economic and social development. Meanwhile, the Regional Coordinated Development Strategy defines that mutual promotion, complementary advantages, and common development are the spatial purpose of China’s regional economic and social development. Therefore, under these two strategies, the best way to realize the coordinated regional development of the demand side and supply side, thereby improving regional and even national competitiveness, is to build a regional innovation system with coordinated development of demand and supply, which also helps to reach the sustainable development of regional innovation system.

Due to the fact that the Yangtze River Economic Belt (YREB) is the only first-tier development axis that spans Eastern China, Central China, and Western China, and that it is also the core part of China’s T-shaped land space development pattern (Figure 1), the development of YREB becomes a key purpose of many China’s regional coordinated development strategies, and its development will greatly promote the development of the whole country [11]. Meanwhile, it is also because that it crosses Eastern China, Central China, and Western China, the development of the YREB shows obvious characteristics of “high and strong in the east, low and weak in the west”. Coordinated development about economy, urbanization, industry, and environment has been widely studied in some regions and in YREB [12–15], and research about YREB of the coordinated development often shows obvious spatial characteristics, which is of great inspiration for practice. The coordinated development of innovation system of YREB have rarely been studied; therefore, under the two national strategies, Innovation-driven Development Strategy and Regional Coordinated Development Strategy, the coordinated development between demand and supply in innovation system of YREB may also present significant regional difference and inter-city difference, which may affect the sustainable development of innovation system in YREB.

![Figure 1. The location of Yangtze River Economic Belt in China.](image-url)

The purpose of this paper is to explore the evolution, spatial difference, and the coupling coordination development of the regional innovation system of YREB from the
demand and supply perspective. The main contribution of this paper is as follows: First, it enriches the literature of regional innovation system. By dividing the regional innovation system into the innovation demand subsystem (IDS) and innovation supply subsystem (ISS), we construct an evaluation index system from the two subsystems and measure their development levels in YREB. Secondly, this paper also enriches the literature relating to regional coordinated development. Through analyzing the allometric growth and coupling coordination relationship between regional IDS and regional ISS in YREB, this paper explores the coordination development and allometric growth between IDS and ISS of cities in YREB and further discusses the development in some important cities.

2. Literature Review

In the early 20th century, Schumpeter [1] put forward that innovation refers to the introduction of a new combination of production factors and production conditions into the production system. After experiencing the liner innovation models like classical economics and endogenous growth theory, many scholars believed that elements like innovation and technology cannot be included in theories of hypothetical equilibrium economic and, therefore, researches related to innovation theories and methods gradually changed from the liner perspective to system perspective. The innovation system theory then appeared.

British scholar Freeman [16] first used the expression of the national innovation system and defined it as the network of institutions in public and private sectors whose activities and interactions initiate, import, modify, and diffuse new technologies. Nelson [17] focused on the empirical case studies and defined the national innovation system as the set of institutions whose interactions determine the innovation performance of national firms. Meanwhile, Lundvall and Edquist [18,19] emphasized the importance of theory development, proposing that the national system of innovation is constituted by the institutions and economic structures, affecting the rate and direction of technological change in the society, and the definition of a national innovation system is that the elements and relationships which interact in the production, diffusion, and use of new, and economically useful knowledge. Patel and Pavitt [20] defined a national innovation system as a system of incentives and competencies of national institutions based on which the main trajectories of technological learning in a country are defined. The theory of national innovation system was completed in a report by OECD [21], in which national innovation system was defined as a network structure created by a set of enterprises, universities, and research institutions that contribute to the development and diffusion of new technologies to create, store, and transfer the knowledge, skill, and artefact.

In the 1990s, with the development of economic globalization, boundaries between countries were gradually blurred. There also emerged a number of regional clusters of firms and industries around the world [22]. Therefore, some scholars argued that it is no longer practical to use the country as a research region. Under this circumstance, Cooke et al. [23] emphasized the importance of the region and proposed the regional innovation system, which he defined as an interactive learning system created by enterprises and other institutions through the institutional environment characterized by embeddedness. Similarly, Gertler et al. [24] believed that the innovation system of a specific region consists of a set of institutions, both public and private, producing pervasive and systemic effects that encourage firms within the region to adopt common norms, expectations, values attitudes, and practices. Doloreux et al. [25] defined the regional innovation system as a set of interacting private and public interests, formal institutions, and other organizations that function according to organizational and institutional arrangements and relationships conducive to the generation, use, and dissemination of knowledge. Buesa et al. [26] concluded that a regional innovation system can be defined as a set of networks between public and private agents that interact and give mutual feedback in the specific territory by taking advantage of their own infrastructure, for the purpose of adopting, generating, and extending knowledge and innovations.
Meanwhile, some scholars believed that further enriching the research boundary of the innovation system to study innovation systems was necessary. Italian scholar Malerba [27–29] criticized and questioned the theory of national innovation system and regional innovation system for its fixed geographical boundaries, arguing that innovation system was also affected by technology and industrial development and, therefore, sectoral innovation system was proposed and be defined as a group of firms active in developing, making a sector’s artefact and generating and utilizing a sector’s technologies. As enterprises grow and new technology rises, research in the innovation system has constantly been refined. Research about the technological innovation system also emerged. The technological innovation system was defined by Carlsson and Stankiewicz [30] as a network of agents interacting in the economic or industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology.

As can be seen in the above definitions, the national innovation system and regional innovation system focus on specific geographical areas, while the sectoral innovation system and technological innovation system take interests in specific industrial sectors or technology. Despite that they are different approaches, they are interrelated, i.e., a technological innovation system could operate at the national, regional, and sectoral level [31], and a sectoral innovation system could also be operated at the national and regional level, and all of them can be classified into the theory of innovation system.

Many scholars have further studied the elements and factors of these innovation systems and constructed an index system to evaluate their development. Achibugi and Michie [32] identified six crucial aspects that define the national innovation system, namely, education and training, science and technology capabilities, industrial structure, S&T strengths and weaknesses, interactions within the innovation system, and absorption from abroad. Maskell and Malmberg [2] thought that interactive learning, environment, and embeddedness are the three elements that constitute a regional innovation system. Michael and Christian [33] suggested that public research institutions are key players in the regional innovation system and, therefore, they can be used by policies to stimulate regional development. Buesa et al. [3] believed that enterprises, public administration, innovation supporting infrastructures, and the national or regional innovative environment are the most important factors of regional innovation system. Diez and Kiese [34] thought that manufacturing and service enterprises, knowledge-intensive business services, knowledge production and dissemination institutions, human resources, intermediaries, and regional policy-making and regulating agencies are the six important factors of RIS. Trippl [4] concluded that knowledge infrastructure, business, relation, socio-institution, and governance are the five key determinants of the cross-border regional innovation system. Based on Buesa’s [25] work, Zabala-Iturriagagoitia et al. [5] constructed an evaluation index system of regional innovation system from the regional and productive environment for innovation, the role of universities, the role of civil service, and the role of innovation firms. Based on relevant studies, Pan [6] constructed a national innovation system evaluation system based on the innovation inputs and outputs indicators. Yuan et al. [35] constructed the evaluation index system of China’s provincial regional innovation system and accessed it from knowledge innovation, technological innovation, intermediary services, government regulation, and innovation investment. Rudskaya [7] evaluated the Russian national innovation system based on the knowledge and technology creation stage and the knowledge and technology commercialization stage.

Research about innovation systems is mainly focusing on five topics, which consists of the review of the development of innovation systems and its future [36–38], the research approaches of innovation systems [39–41], the evaluation of innovation systems in different countries, regions, and sectors [42–44], the role of different actors and their interactions in the innovation systems [45,46], and the effect of innovation systems on innovation and economic efficiency [47–49]. Moreover, the research scale is mostly country, region, and sector.
Few innovation system studies are drawn from the innovation demand, innovation supply, or innovation demand and supply perspective. Innovation research concerning the innovation supply is mostly from two perspectives. One is the supply chain perspective about how the development of the supply chain influences the innovation performance, firm development, and economic competitiveness [50–52], as well as the innovation of the supply chain itself. i.e., in the fields of operations management, marketing, innovation system, psychology, and the supply network perspective. Another one is the supply networks perspective, which is often about the effect of the supply network on innovation [53–55]. As demand is widely considered as a key driver for innovation, the effect of demand and demand-pull policy on the development of different sectoral, industrial innovation [56,57], and the interaction between demand-pull and technology-push [58–60] are widely studied in the innovation demand literature. There is only a few innovation research concerning both demand and supply, which is often about the effect of the supply network on innovation [45,61,62].

Based on the existing researches, studies about innovation systems from the demand and supply perspective are rare. Therefore, in this paper, by dividing the innovation system into IDS and ISS, we construct an evaluation index system of innovation system from the two perspectives and measure their development and coordination development.

3. Analytical Framework and Methods

3.1. Analytical Framework

As discussed above, this paper intends to evaluate the innovation system from the demand and supply perspective. To accomplish this, a conceptual framework of an innovation system based on the demand and supply needs to be constructed. Based on the system theory of demand and supply, the innovation system can be decomposed into two subsystems, namely the IDS and the ISS. Moreover, the conceptual framework of IDS and ISS draws upon the literature review above.

The innovation demand demonstrates the influence of social, economic, and cultural development on innovation activities. A society with great performance on social, economic, and cultural development requires a high-quality innovation supply, and in return, the high-quality innovation supply helps to achieve the comprehensive development of the society, economy, and culture. Therefore, the IDS can be constructed from three levels, namely, economic demand, social demand, and cultural demand. The economic demand describes the overall economic situation of a society, while the social demand focuses on the social situation concerning people directly [32,63–65]. Cultural demand reflects a higher level of innovation demand [66–68].

The innovation supply indicates the capability and the quality of innovation activities, and based on the literature review, it is manifested as the ability of innovation subjects, the quality of innovation resources, as well as the adequacy of innovation infrastructure, environment, and institution [3,4,23,33]. In general, the innovation infrastructure, environment, and the institution all can be summarized into the environment supply because they are all be provided to the innovation subjects to create the innovation supply [3,4,33]. Thus, the index system of ISS is constructed from three dimensions, namely, the resource supply, the subject supply, as well as the environment supply. Human resources, capital, and technology are long been recognized as important resources that generate innovation [2,35,69]. Subjects that promote innovation are usually enterprises, colleges and universities, and organizations [33,34,70,71]. The environment related to the supply of innovation is usually about the institutional environment, the cultural environment, and the Internet [2–4]. Political stability is a kind of institutional environment factor that can greatly shape the innovation activities and performance [72,73], and because that the cities we studied are under the same political stability environment, this institutional factor was not taken into consideration. Due to the fact that under China’s context, cities with different administrative levels have a different status in the development of innovation and innovation systems, and cities with high administrative levels attach more attention to the development of
innovation systems. Therefore, we set the institutional variable as a dummy variable, where the 11 provincial capital cities and municipalities took the value 1, and the rest cities took the value 0.

The selection of specific indicators should combine scientificity and operability, as well as representativeness and quantifiability. Based on the above discussion, we constructed the evaluation index system of innovation demand subsystem from the economic demand, social demand, and cultural demand perspectives, which consists of 8 evaluation indicators. The evaluation index system of ISS was constructed from resource supply, subject supply, and environment supply perspectives and consists of 9 evaluation indicators. The index system of innovation system from IDS and ISS is shown in Table 1.

Table 1. Index system of innovation system from the demand and supply perspective.

| Purpose                  | 1st Grade Index | 2nd Grade Index | 3rd Grade Index | Indicator                                      | Overall Weight |
|--------------------------|-----------------|-----------------|-----------------|-----------------------------------------------|----------------|
| IDS                      | Economic demand | Economic demand scale | Gross regional product (yuan) | 0.1503                                       |
|                          |                 | economic demand structure | Output value of tertiary industry (yuan) | 0.2566                                       |
|                          |                 | Economic demand opening degree | Amount of foreign capital utilized (million US$) | 0.1219                                       |
| Innovation system        | Social demand   | Social demand scale | Household population at year-end | 0.0477                                       |
|                          |                 | Social demand structure | Urbanization rate (%) | 0.1515                                       |
|                          |                 | Social demand situation | Rate of employment (%) | 0.0557                                       |
|                          | Cultural demand | Cultural demand scale | Urban education level (year) Engel coefficient of urban residents (%) | 0.1136                                       |
|                          |                 | Cultural demand structure |                                        | 0.0737                                       |
| ISS                      | Resource supply | Talent supply | Number of undergraduate students in regular HEIs | 0.1678                                       |
|                          |                 | Capital supply | Expenditure for science and technology (yuan) | 0.1278                                       |
|                          |                 | Technological supply | Number of patent authorizations | 0.1133                                       |
To show the different importance of different indicators, this paper endowed different indicators with different weights through the combination of the subject evaluation method and object evaluation method. The analytic hierarchy process (AHP) is a subjective weighting method that combines qualitative analysis and quantitative analysis, which has high reliability but may often lack objectivity. The entropy weight method is an objective weighting method based on the information provided by data. Therefore, by combining the AHP \[74\] and entropy weight method \[75\], the overall weight of each indicator is calculated (see Table 1). The weight determined by the AHP method and entropy weight method is $W_S = (W_{S1}, W_{S2}, \ldots, W_{Sm})$ and $W_O = (W_{O1}, W_{O2}, \ldots, W_{Om})$. The calculation of the overall weight, combined subjective weight, and the objective weight of indicators is expressed as follows:

$$W_j = \frac{W_j^S \times W_j^O}{\sum_{j=1}^{m} \sqrt{W_j^S \times W_j^O}}, j = 1, 2, \ldots, m$$

where $W_j$ represent the overall weight of indicator $j$. Then, in order to compare the index value directly, data normalization was applied through the following equation, where $x_{ij}$ and $Z_{ij}$ represent the original and normalized data of indicator $j$ at city $i$:

$$Z_{ij} = \frac{x_{ij} - \min_{1 \leq i \leq n} (x_{ij})}{\max_{1 \leq i \leq n} (x_{ij}) - \min_{1 \leq i \leq n} (x_{ij})}, i = 1, 2, \ldots, n, j = 1, 2, \ldots, m$$

After the data normalization, the comprehensive development value of the subsystem (IDS and ISS) can be calculated by the following equation:

$$I_{dema,it} = \sum_{i=1}^{n} W_i Z_{ij}$$
\[ I_{\text{supp},it} = \sum_{i=1}^{n} W_j Z_{ij} \]

where \( I_{\text{dem},it} \) and \( I_{\text{supp},it} \) represent the comprehensive development value of the IDS and ISS of city \( i \) at year \( t \).

Chinese statistical data are often available after a one-year delay, and the statistical data of autonomous prefecture releases even later. Therefore, the research period of this paper is from 2007 to 2017. All the statistical data are derived from the China City Statistical Yearbook, statistical yearbook of cities and provinces, and official websites.

3.2. Study Area

The YREB is a major national policy development area in China, and it consists of 9 provinces (i.e., Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Sichuan, Guizhou, and Yunnan) and 2 municipalities (i.e., Shanghai, Chongqing) (see Figure 2), with its 2.1 million square kilometers area accounting for 21% of China’s land area. The population density and economic density are 4.5 and 6.2 times the national average. It contains 126 cities, and the cities are the municipalities, provincial capital, prefecture-level cities, and autonomous prefectures, and do not include county-level cities. The 126 cities are divided into three regions according to the river basin, namely the upper reaches of YREB, the middle reaches of YREB, and the lower reaches of YREB. The upper reaches of YREB contains 47 cities within Sichuan, Guizhou, and Yunnan Provinces as well as the municipality, Chongqing, and Chongqing is the core city. The middle reaches of YREB includes 38 cities within Jiangxi, Hubei, and Hunan Provinces, and Wuhan is the core city. The lower reaches of YREB contains 41 cities within Jiangsu, Zhejiang, and Anhui Provinces as well as the municipality, Shanghai, and Shanghai is the core city.

Figure 2. The Yangtze River Economic Belt.

As discussed before, the YREB is an important area in both the national development and in the Innovation-driven development and Regional Coordinated Development Strategies, in the meantime, the Development of YREB has been identified as one of the three major national regional development strategies of China. Because of that, the three major regions it spans are very different in both the natural and social aspects, and there are no joint regional authorities to manage the overall development. It shows obvious different characteristics in the development of innovation systems. The YREB is, therefore, a typical study region to explore the development of innovation systems and their spatial differences and to further study the coordinated development of innovation systems. The study area is shown in Figure 2.
3.3. Methods

3.3.1. Allometric Growth Model

The law of allometric growth originates from biology, and it explores the differential growth rates of the parts of a living organism’s body [76,77]. It was introduced into geography by Naroll and Bertalanffy [78] to study the relationship between urban and rural populations. Gould [79] defined it as the differences in proportions correlated with changes in the absolute magnitude of the total organism or of the specific parts under consideration. Based on the above research, Beckmann proposed the allometric growth model to describe the ratio of the relative growth rate of the populations. Many scholars used the allometric growth law to study the population and the urban area [78,80–82]. In general, allometric growth means the ratio between the growth rate of a part in a system and the growth rate of other parts in the same system. The equation is usually expressed as followed:

\[
\frac{1}{y} \frac{dy}{dt} = b \frac{1}{x} \frac{dx}{dt}
\]

\(y\) refers to the measure of part or subsystem, and \(x\) is the measure of other part or subsystem. \(b\) is allometric growth coefficient, also called scaling exponent, which represents the relative ratio of the growth rate between \(x\) and \(y\). According to the allometric growth law, too big or too small of coefficient \(b\) will lead to the vanishment of the related element, thus losing the diversity and complexity of the whole system [78]. After mathematical changes, it can be transferred into the following power exponential form:

\[y = ax^b\]

We made a hypothesis that there exists a correlation and mathematical relation between IDS and ISS. In the above equation, let \(x_i = x\), which represents the comprehensive development value of IDS; let \(y_j = y\), which represents the comprehensive development value of ISS. Then, we can get the allometric growth model of innovation demand subsystem and innovation supply subsystem as follows:

\[y = ax^b\]

When \(b > 1\), which is called positive allometric, the ISS has a higher growth rate than the IDS.

When \(b = 1\), which is called isometry, the IDS and the ISS have the same growth rate.

When \(b < 1\), which is called negative allometric, the IDS has a higher growth rate than the ISS.

3.3.2. Coupling Coordination Model

The coupling degree comes from the physics concept of capacitive coupling, and it measures the dynamic relationship among subsystems that are interdependent and interact. When a system has \(n\) subsystems, its mathematical formula is described as follow:

\[C_n = \left[ \frac{U_1 U_2 \ldots U_n}{\prod_{i \neq j} (U_i + U_j)} \right]^{1/n}\]

where \(U_i\) and \(U_j\) represent the value of the \(i\)-th and \(j\)-th subsystem, and \(n\) represents the number of the subsystems. For the case of the two subsystems, IDS and ISS in this paper, the calculation form then can be expressed as follows:

\[C_{it} = 2 \sqrt{\frac{f(x)_{dema,it} \times g(y)_{supp,it}}{(f(x)_{dema,it} + g(y)_{supp,it})^2}}\]
where \( C_{it} \) represents the coupling degree of city \( i \) at year \( t \). \( f(x) \) and \( g(y) \) represent the value of IDS and ISS, respectively.

Although the coupling degree can reflect the strength of the interaction between subsystems, it cannot show the overall coordinated development level of subsystems. Therefore, the coupling coordination degree model is introduced to analyze the coordinated development degree between IDS and urban ISS. Its calculation formula is as follows:

\[
D_{it} = \sqrt{C_{it} \times T_{it}}
\]

\[
T_{it} = \alpha f(x)_{dema,it} + \beta g(y)_{supp,it}
\]

where \( D_{it} \) represents the coupling coordination degree of the city \( i \) at the time \( t \) and \( D_{it} \in (0, 1) \). The higher \( D_{it} \) is, the more coordinated the development between IDS and ISS is, which means that the IDS and ISS both have a high level and balanced development. \( \alpha \) and \( \beta \) are undetermined coefficients, and according to previous studies, we let \( \alpha = \beta = \frac{1}{2} \). The coordinated development levels were divided into ten classes according to the values of coupling coordination degree. The discriminating standard is shown in Table 2.

### Table 2. The discriminating standard of coupling coordination degree.

| D     | Class                              |
|-------|------------------------------------|
| 0–0.09| Extremely uncoordinated development |
| 0.10–0.19| Seriously uncoordinated development |
| 0.20–0.29| Moderately uncoordinated development |
| 0.30–0.39| Slightly uncoordinated development |
| 0.40–0.49| Barely uncoordinated development |
| 0.40–0.59| Barely coordinated development |
| 0.60–0.69| Slightly coordinated development |
| 0.70–0.79| Moderately coordinated development |
| 0.80–0.89| Favorably coordinated development |
| 0.90–1.00| Superiorly coordinated development |

### 4. Results

#### 4.1. Development of Innovation Demand Subsystem

4.1.1. Descriptive Characteristics of IDS Development Value

During the period of 2007 to 2017, the minimum, maximum, and average IDS development value of cities in YREB all increased steadily (see Table 3), indicating that the IDS had developed significantly over time. The range (R) and standard deviation (SD) of the IDS development values of all cities in YREB showed an upward trend, and the Gini Coefficients decreased from 0.2020 in 2007 to 0.1704 in 2017. The above figures show that the development of IDSs among cities in YREB were relatively equal, however, the development gap showed a slight expanding tendency.

### Table 3. Statistical characteristics of the comprehensive development value of innovation demand subsystem (IDS) in the Yangtze River Economic Belt (YREB).

| Year | Min     | Max     | Average | R      | SD     | Gini   | Global Moran’s I |
|------|---------|---------|---------|--------|--------|--------|------------------|
| 2007 | 0.0043  | 0.5507  | 0.1805  | 0.5464 | 0.0712 | 0.2070 | 0.4573           |
| 2012 | 0.0520  | 0.7132  | 0.2216  | 0.6612 | 0.0879 | 0.1957 | 0.3679           |
| 2017 | 0.1313  | 0.9148  | 0.2825  | 0.7835 | 0.1040 | 0.1704 | 0.2962           |

Global Moran’s I value of IDS values were between 0.29 to 0.45, which indicates that there existed spatial clusters and that the high-value regions tended to be located near high-value regions, low values near low values. Meanwhile, the Global Moran’s I value showed a decreasing trend, demonstrating that the spatial aggregation tends to decrease in the future.
In general, the IDS of cities in YREB continued to develop during the study period. Meanwhile, the development gap of IDS among cities in YREB showed a relatively expanding tendency.

4.1.2. Spatial Distribution of IDS Development Value

In 2007, the IDS values of only 7 cities were above 0.3, and except Chongqing, the other 6 cities were all located in the lower reaches of YREB. The IDS development value of Shanghai was 0.5507, much higher than the second, Suzhou, ranking first and far exceeding other cities. The IDS development value of Chongqing, the core city of upper reaches, ranked sixth, and Wuhan as the core city of middle reaches, ranked ninth. In the top 15 cities of IDS development value, up to 11 cities belong to the lower reaches of YREB.

In terms of spatial distribution, as shown in Figure 3, only one relatively high-value region can be observed in the middle east of lower reaches of YREB, and the region mainly consists of Shanghai and its surrounding areas.

During the period of 2007 to 2012, a number of cities saw obvious development of the IDS. In 2012, Shanghai still ranked first in the ranking of IDS development value. The top two cities remained unchanged. The ranking of Chongqing, Chengdu, and Wuhan improved to third, fourth, and sixth, respectively. As can be seen in Table 4, among the top 15 cities of IDS development value, the number of cities in the lower reaches of YREB dropped to 9, and their overall position declined a little. With regards to the spatial distribution, as is shown in Figure 3, there were two relatively high-value regions. One was still in the middle east of the lower reaches of YREB, and the other was in the west part of the middle reaches of YREB. It is noteworthy that cities around Wuhan all showed relatively bad performance in the development of IDS, forming a low-value circle region in the peripheral area of Wuhan.
Table 4. The top 15 cities in IDS development value ranking in the year 2007, 2012, and 2017.

| Rank | 2007 Value | 2012 Value | 2017 Value |
|------|------------|------------|------------|
| 1    | 0.5507     | 0.7132     | 0.9148     |
| 2    | 0.3624     | 0.4853     | 0.6183     |
| 3    | 0.3512     | 0.4657     | 0.5582     |
| 4    | 0.3362     | 0.4383     | 0.5551     |
| 5    | 0.3127     | 0.4266     | 0.5406     |
| 6    | 0.3211     | 0.4182     | 0.5359     |
| 7    | 0.3028     | 0.4182     | 0.5216     |
| 8    | 0.2999     | 0.3961     | 0.4903     |
| 9    | 0.2982     | 0.3619     | 0.4656     |
| 10   | 0.2858     | 0.3419     | 0.4427     |
| 11   | 0.2780     | 0.3304     | 0.3990     |
| 12   | 0.2708     | 0.3268     | 0.3971     |
| 13   | 0.2611     | 0.3257     | 0.3946     |
| 14   | 0.2609     | 0.3104     | 0.3820     |
| 15   | 0.2584     | 0.3086     | 0.3727     |

In the period of 2012 to 2017, the IDS of most cities in YREB had further developed. In 2017, the IDS of Shanghai developed to a very high level and its value remained the absolute first in the ranking. The ranking of the 2 core cities of middle and upper reaches of YREB, Chongqing and Wuhan, improved to second and third, respectively. There were still 9 cities out of the top 15 cities that belong to the lower reaches of YREB, but compared to that in 2012, their overall position dropped. In terms of the spatial distribution, there existed one high-value region and one relatively high-value region. The high-value region was still concentrated in the east part of the lower reaches of YREB, and compared with the previous period, it expanded a little to the south and north. The relatively high-value region was a wide continuous area from the east part of the upper reaches of YREB to the west of the lower reaches of YREB.

4.2. Development of Innovation Supply Subsystem

4.2.1. Descriptive Statistics of ISS Development Value

During the period of 2007 to 2017, the minimum, maximum, and average ISS value raised slightly, demonstrating that the ISS had certain development over the study period, as shown in Table 5. The range and the standard deviation of the ISS value also showed a slightly increasing trend during the period, and Gini coefficients were all above 0.55, which means that the development gap of ISS among cities in YREB was huge.

Table 5. Statistical characteristics of comprehensive development value of innovation supply subsystem (ISS) in YREB.

| Year | Min  | Max  | Average | R     | SD   | Gini  | Global Moran’s I |
|------|------|------|---------|-------|------|-------|------------------|
| 2007 | 0.0001 | 0.6826 | 0.0476 | 0.6825 | 0.0882 | 0.6625 | 0.1436          |
| 2012 | 0.0003 | 0.6951 | 0.0614 | 0.6948 | 0.1038 | 0.6398 | 0.1599          |
| 2017 | 0.0052 | 0.7518 | 0.0777 | 0.7466 | 0.1154 | 0.5753 | 0.1166          |

Global Moran’s I value of cities in YREB was all positive and between 0.1 to 0.2 during the whole study period, indicating that the distribution of the ISS value showed a very low level of positive correlation. However, the Global Moran’s I value showed a fluctuated downward trend, indicating that the spatial disparity tends to be narrowed in the future, and the results all passed the 0.01 significance test.

In general, the ISS of cities in YREB had certain development during the study period. Meanwhile, the development gap between cities was huge, and small spatial clusters can be observed in the distribution of the ISS development value in the study period.
4.2.2. Spatial Distribution of ISS Development Value

In 2007, only Shanghai and its surrounding cities, as well as some other provincial capital cities (Wuhan, Chengdu, Chongqing, Changsha, Nanchang, Kunming), had obvious development in ISS. The ISS development value of Shanghai was 0.6826, more than twice that of the second, and Wuhan ranked first in YREB and developed much faster than other cities. The ranking of Chengdu and Chongqing were fifth and sixth. Among the top 15 cities of ISS value, 9 cities were cities in the lower reaches of YREB, and the rest were provincial capital cities (see Table 6). In respect of spatial distribution, as shown in Figure 4, there existed one small area of relatively high value concentrating in Shanghai and its surrounding areas, while the other areas were a vast low-value region.

### Table 6. The top 15 cities in ISS value ranking in the year 2007, 2012, and 2017.

| Rank | 2007 Value | 2012 Value | 2017 Value |
|------|------------|------------|------------|
| 1    | Shanghai   | 0.6826     | Shanghai   | 0.6951     | Shanghai   | 0.7518     |
| 2    | Wuhan      | 0.3349     | Wuxi       | 0.4478     | Chongqing  | 0.5177     |
| 3    | Hangzhou   | 0.3076     | Chongqing  | 0.4060     | Wuhan      | 0.5103     |
| 4    | Nanjing    | 0.3025     | Chengdu    | 0.3643     | Chengdu    | 0.4561     |
| 5    | Chengdu    | 0.2752     | Suzhou     | 0.3608     | Nanjing    | 0.4003     |
| 6    | Chongqing  | 0.2741     | Hangzhou   | 0.3578     | Hangzhou   | 0.3874     |
| 7    | Ningbo     | 0.2362     | Nanjing    | 0.3523     | Suzhou     | 0.3491     |
| 8    | Changsha   | 0.2056     | Ningbo     | 0.2580     | Changsha   | 0.2892     |
| 9    | Suzhou     | 0.1846     | Changsha   | 0.2491     | Hefei      | 0.2665     |
| 10   | Nanchang   | 0.1779     | Hefei      | 0.2099     | Ningbo     | 0.2623     |
| 11   | Hefei      | 0.1388     | Wuxi       | 0.1891     | Nanchang   | 0.2395     |
| 12   | Kunming    | 0.1299     | Nanchang   | 0.1844     | Kunming    | 0.2158     |
| 13   | Wuxi       | 0.1154     | Kunming    | 0.1628     | Wuxi       | 0.1802     |
| 14   | Wenzhou    | 0.1136     | Nantong    | 0.1415     | Wenzhou    | 0.1596     |
| 15   | Changzhou  | 0.0973     | Guiyang    | 0.1332     | Guiyang    | 0.1551     |

Figure 4. The spatial distribution of the ISS value in the year (a) 2007, (b) 2012, and (c) 2017.

During the period of 2007–2012, the ISS developed slowly, and the situation was quite similar to that in 2007. As shown in Table 6, in 2012, Shanghai and Wuhan still ranked first and second, while their development gap was narrowed. Chongqing and Chengdu surpassing other cities, ranked third and fourth. Among the top 15 cities, the number...
of cities belongs to the lower reaches of YREB dropped to 8. With regards to the spatial
distribution, as can be seen in Figure 4, it is quite like the situation in 2007, and there existed
only a small relatively high-value region in the middle east of lower reaches of YREB.

During the period of 2012–2017, the ISS showed relatively significant development
compared to the previous period. Some non-provincial capital cities and non-municipality
cities had their ISS development value developed. In 2017, Shanghai remained the absolute
first, with its ISS development value increased from 0.6951 in 2012 to 0.7518 in 2017.
Surpassing Wuhan, the ranking of Chengdu raised to the second, with its ISS value
changed from 0.4060 to 0.5177. Among the top 15 cities, there were still 8 cities that belong
to the lower researches of YREB. With respect to the spatial distribution, the low-value
region and high-value region were quite like the previous period.

4.3. Measure of Coordinated Development

4.3.1. Allometric Growth Situation

By applying the IDS development value and ISS development value to the equation of
allometric growth, we calculated the allometric growth equations of the 126 cities in YREB.
A total of 93 cities out of the total 126 cities got positive allometric results, which
means that their ISS had a higher growth rate than their IDS. Only 33 cities got the negative
allometric results, which means that the development rate of their ISS lagged behind
the development rate of IDS, further indicating that the IDS and ISS had imbalanced
development. Although the development rate of ISS was much higher than the IDS in most
cities, the IDS of most cities had developed to a relatively mature period, and the ISS could
not meet the need of IDS.

As shown in Table 7, only 3 cities out of the 11 provincial capital cities and mu-
nicipalities got the positive allometric results, namely, Guiyang, Kunming, and Hefei,
demonstrating that their ISS had a higher growth speed than their IDS. Moreover, the
development level of IDS and ISS of the 3 cities were low compared to the other 8 provin-
cial capital cities and municipalities. The scaling exponent of Chengdu and Nanjing were
0.8433 and 0.7076, indicating that the development rate of its IDS and ISS was relatively
consistent, while the scaling exponent of Shanghai and Chengdu were all below 0.20, which
shows that their IDS developed much faster than their ISS, indicating the IDS and ISS had
uncoordinated development. The scaling exponents of Wuhan, Changsha, Hangzhou, and
Nanchang were between 0.4 to 0.7, demonstrating that their IDS had a higher growth speed
than their ISS.

| City    | Scaling Exponent |
|---------|------------------|
| Guiyang | 2.6625           |
| Kunming | 1.0527           |
| Hefei   | 1.4092           |
| Chengdu | 0.8433           |
| Nanjing | 0.7076           |
| Wuhan   | 0.6775           |
| Changsha| 0.6255           |
| Hangzhou| 0.4834           |
| Nanchang| 0.4301           |
| Shanghai| 0.1896           |
| Chongqing| 0.9330         |

4.3.2. Development of Coupling Coordination between IDS and ISS

Descriptive Characteristics of Coupling Coordination Degrees

As can be seen in Table 8, the minimum and maximum coupling coordination de-
gree, average coupling coordination degree all saw an increase during the study period,
which indicates that the coordinated relationship between IDS and ISS in YREB improved
over time. The range and the standard deviation of the coupling coordination degree in
YREB were relatively high and showed a slightly upward trend. The Gini coefficient was between 0.15 and 0.25 during the whole study period. The above figures show that the coupling coordination level was relatively equal between cities in YREB during the study period; however, the development gap of coordinated development between cities had an expansion tendency.

Table 8. Statistical characteristics of coupling coordination degree of IDS and ISS in YREB.

| Year | Min    | Max    | Average | R      | SD    | Gini  | Global Moran’s I |
|------|--------|--------|---------|--------|-------|-------|------------------|
| 2007 | 0.0566 | 0.7830 | 0.2608  | 0.7264 | 0.1157| 0.2250| 0.3297           |
| 2012 | 0.0627 | 0.8391 | 0.2975  | 0.7764 | 0.1270| 0.2150| 0.3208           |
| 2017 | 0.1713 | 0.9107 | 0.3467  | 0.7393 | 0.1273| 0.1814| 0.2546           |

Global Moran’s I value of the coupling coordination degree during the study period was between 0.25 and 0.35, indicating that there existed positive spatial correlation in the distribution of coupling coordination degrees, which means that high coupling coordination degree regions tended to be located near high degree regions, medium nears medium values, and low nears low.

In general, the coordinated relationship between IDS and ISS saw obvious improvement during the study period. However, the development gap of coordination development among cities were huge, and spatial clusters can be observed during the study period.

Spatial Distribution of Coupling Coordination Degrees

In 2007 and before, the majority of cities in YREB were at the moderately uncoordinated development phase. Cities at the slightly uncoordinated development phase, barely uncoordinated development phase, and barely coordinated development phase accounted for 22.4% of the total. Shanghai with the highest coupling coordination degree was at the moderately coordinated development phase. Four provincial capital cities and 1 municipality, Nanjing, Hangzhou, Wuhan, Chongqing, and Chengdu, were at the barely coordinated development phase. Meanwhile, Changsha, Nanchang, Hefei, Kunming, as well as other three cities in the lower reaches of YREB were all at the barely uncoordinated development phase. In general, the IDS and ISS of most cities have unbalanced and low-quality development in 2007. In terms of spatial distribution, as can be seen in Figure 5, there existed only a relatively high coupling coordination degree region concentrated in the eastern coastal area of the lower reaches of YREB.

During the period of 2007 to 2012, the coupling coordination situation saw an overall improvement. As shown in Table 9, although the number of cities at the moderately uncoordinated development phase still accounted for up to 50.7% of the total, the proportion of cities in the seriously uncoordinated development phase had dropped a lot. Moreover, the number of cities in the slightly uncoordinated development phase increased to 22. Shanghai remained the most coordinated development city between IDS and ISS and was the only city at the favorably coordinated development phase. Chongqing, Wuhan, Suzhou, Chengdu, Nanjing, and Hangzhou were the 5 provincial capital cities and 1 municipality developed to the slightly coordinated development phase. Changsha and Hefei developed to the barely coordinated development phase. Nanchang, Kunming, and Guiyang were at the barely uncoordinated development phase. With respect to the spatial distribution, as shown in Figure 5, relatively high values were still concentrated in the eastern coast of the lower reaches of YREB. However, compared with the previous period, the high-value region expanded a little. It is worth noting that there was a relatively low-value city circle around Wuhan, with them all at the seriously uncoordinated development phase and its outer cities all at the moderately uncoordinated development phase, indicating that Wuhan may have the siphoning effect toward the cities around it in the coordination development of IDS and ISS.
Figure 5. The spatial distribution of coupling coordination degree in the year (a) 2007, (b) 2012, and (c) 2017.

Table 9. Number of cities at different coupling coordination phase in the year 2007, 2012, and 2017.

| D         | Class                        | 2007 | 2012 | 2017 |
|-----------|------------------------------|------|------|------|
| 0–0.09    | Extremely uncoordinated development | 3    | 2    | 0    |
| 0.10–0.19 | Seriously uncoordinated development | 31   | 17   | 3    |
| 0.20–0.29 | Moderately uncoordinated development | 61   | 64   | 53   |
| 0.30–0.39 | Slightly uncoordinated development | 14   | 22   | 43   |
| 0.40–0.49 | Barely uncoordinated development | 7    | 10   | 14   |
| 0.50–0.59 | Barely coordinated development | 7    | 4    | 5    |
| 0.60–0.69 | Slightly coordinated development | 0    | 6    | 4    |
| 0.70–0.79 | Moderately coordinated development | 1    | 0    | 3    |
| 0.80–0.89 | Favorably coordinated development | 0    | 1    | 0    |
| 0.90–1.00 | Superiorly coordinated development | 0    | 0    | 1    |

In the period of 2012 to 2017, the quality of both IDS and ISS showed an improvement, and obvious development in coupling coordination between IDS and ISS of cities in YREB can be observed. The proportion of cities in the extremely, seriously, or moderately uncoordinated development phase dropped rapidly, as can be seen in Table 9. Meanwhile, the number of cities in the slightly or barely uncoordinated development phase increased to 57. The coupling coordination degree of Shanghai raised to 0.9106, and it became the only city at the superiorly balanced development phase. Chongqing, Wuhan, and Chengdu were the only three cities that developed to the moderately coordinated development phase. Nanjing, Hangzhou, Suzhou, and Changsha were the 4 cities at the slightly coordinated development phase. Hefei, Nanchang, and Kunming were just developed to the barely coordinated development phase. With regards to the spatial distribution, as manifested in
Figure 5, there existed a high-value region concentrated in the east of the lower reaches of YREB and a relatively high-value region concentrated in most part of the middle reaches of YREB. Some cities around Wuhan were still underdeveloped in coupling coordination development compared to Wuhan and its surrounding cities.

5. Summary and Conclusions

By dividing the regional innovation system into IDS and ISS, we established an evaluation index system of the innovation system, and then we evaluated the development value of IDS and ISS of the 126 cities in YREB, as well as the allometric growth and coupling coordination relationship between IDS and ISS in the period of 2007 to 2017. Furthermore, we found that:

The development value of IDS and ISS both showed an increasing trend during the study period. The development gap of IDS among cities was relatively balanced and showed an obvious agglomeration effect. However, the development gap of ISS among cities was huge, and the distribution of ISS value demonstrated a low level of positive correlation. Shanghai had the highest development value of both IDS and ISS, which showed a positive effect on the development of IDS and ISS of its surrounding cities. However, Wuhan, as the core city of the middle reaches of the YREB, showed a limited effect on the development of the innovation system of its surrounding cities. The core cities of the upper reaches of YREB, Chongqing, performed great in the IDS and ISS, showing a certain positive effect on the development of their surrounding cities. The high value of IDS and ISS were both mostly concentrated in the east part of the lower reaches of the YREB.

During the study period, the ISS of most cities had a higher growth rate than the IDS. Meanwhile, even though the ISS had a higher growth speed, the IDS of these cities had developed to a relatively mature period, and that the ISS could not meet the need of the IDS, which means there existed very uncoordinated development between IDS and ISS in many cities. The IDS had a higher growth speed than the ISS in 33 cities, which consists of the three core cities of the lower, middle, and upper reaches of YREB, namely, Shanghai, Wuhan, and Chongqing. The coupling coordination degree also showed an increasing trend during the study period, which developed from most cities that were at the seriously or moderately uncoordinated development phase to most cities that were at the moderately or slightly uncoordinated development phase. Meanwhile, the coordination development gap of IDS and ISS between cities in YREB was quite balanced, and the coordination development showed a certain level of positive spatial correlation. Shanghai had developed to the superiorly coordinated development phase at the end of the study period. Chongqing, Wuhan both developed to the moderately coordinated development phase at the end of the study period.

It is certain that the development of IDS and ISS and their coordinated development will affect the sustainable development of urban innovation, thereby further affecting the social–economic development, and even the overall national strength and international competitiveness. Therefore, under the context of Supply-side Reform in China, efforts are needed to develop both the IDS and ISS and to create effective and quality innovation supply to meet the innovation demand, thereby reaching the sustainable development of the regional innovation system. Since there existed huge disparity in the development pace of the IDS and ISS among the upper reaches, middle reaches, and lower reaches of YREB, as well as among some cities, the three parts of YREB and different cities should interact more in both IDS and ISS to narrow the development gap and reach to the coordinated and balanced development in the future, especially between upper reaches and lower reaches and between Wuhan and its surrounding cities, which is of great significance to the coordinated development of the Eastern, Central, and Western China.

Under the international context of globalization, innovation has now become an important role in both economic development and technology advancement, and the development of an innovation system can greatly promote economic and technological progress. Existing studies on innovation systems are mostly on its components, structure,
function, and evaluation [2–7], in which scholars have considered the innovation system from a comprehensive angle. By dividing the innovation system into innovation demand subsystem and innovation supply subsystem, this study was able to study the innovation system from a new angle, and that is to study the internal development of the innovation system from a demand and supply perspective. Results of this study show that there existed imbalanced development of IDS and ISS in YREB, and it affected the sustainable and coordinated development of the innovation system, which brings inspiration to the research of innovation system from the demand and supply perspective and further explore its coordinated and sustainable development.

Several limitations and directions for future studies should be acknowledged. First, this paper attempted to construct the evaluation index system of regional innovation system from the demand and supply perspective, and in detail, from the economic demand, social demand, cultural demand, resource supply, subject supply, and environment supply, based on previous studies. Therefore, we may lose sight of some other important aspects that contribute to the regional innovation system. Secondly, although this paper explored the regional innovation system from a new perspective, the demand and supply perspective, it only focused on the evaluation of the innovation system and did not further study the influence mechanism behind it. At last, the study area of this paper is the YREB, and the innovation systems of some important urban agglomerations in YREB were not be discussed. Further studies can be made concerning the innovation system of urban agglomeration from the demand and supply perspective.

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