Synergy of the innovation system in the Yangtze River Economic Belt

Yan Liu¹, Min Lei, Jie Sun and Xin Zhang
Beijing Wuzi University, No. 321 Fuhe Street, Tongzhou District, Beijing, China

¹Email: bitliuyan@sina.com

Abstract. On the basis of the principle of order parameters of synergy, a synergy model of the financial-technological-industrial collaborative innovation system in the Yangtze River Economic Belt was constructed. Panel data for the financial structure, technological innovation, and industrial innovation in the Yangtze River Economic Belt for the period from 2011 to 2016 were used to analyze the degree of synergy within each subsystem of the innovation system and between the subsystems and measure the corresponding levels of synergy. The research showed that the financial-technological-industrial subsystems in the Yangtze River Economic Belt were basically in an orderly state, and the Jiangsu subsystem exhibited the best synergy, followed by Shanghai and Zhejiang, whereas that of Yunnan was poor. The overall economic cooperation of the Yangtze River Economic Belt is not ideal, and the level of synergy fluctuates greatly.

1. Introduction
The report of the 19th National Congress of the Communist Party of China pointed out that "socialism with Chinese characteristics has entered a new era", in which it is essential to "build a modern economic system" and "accelerate the construction of an innovative country" is one of the six tasks of the modern economic system. The innovation system is a composite system composed of many subsystems. In a system, the subsystems are properly coordinated and move toward the same goal in the same direction, and the power of the subsystems can be brought together, so that the overall function is greater than the sum of the functions of the subsystems. The combination of the functions of the subsystems thus gives rise to a synergistic effect and results in a "1+1>2" phenomenon [1]. In view of this, the degree of synergy between each subsystem of the innovation system has become a popular issue in current research. Existing research has mainly focused on the industrial innovation subsystems and technological innovation subsystems etc, and has ignored the requirement for coordinated development of financial structures and the innovation system. A good financial system can enable large-scale long-term effects via financial investment and by providing long-term incentive functions, risk dispersion functions, and market sharing opportunities can promote the long-term, stable, and continuous innovation behavior [2]. This paper therefore divides the innovation system into the financial structure subsystem, scientific and technological innovation subsystems etc, and has ignored the requirement for coordinated development of financial structures and the innovation system. A good financial system can enable large-scale long-term effects via financial investment and by providing long-term incentive functions, risk dispersion functions, and market sharing opportunities can promote the long-term, stable, and continuous innovation behavior [2]. This paper therefore divides the innovation system into the financial structure subsystem, scientific and technological innovation subsystems, and industrial innovation subsystem, in order to better promote innovation and development.

The Yangtze River Economic Belt spans the eastern, central, and western regions of China, covers 11 provinces (cities), namely Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Yunnan and Guizhou, and has a population of 600 million. With an area of about 2.05 million square kilometers, its per capita GDP has exceeded the national average since 2016. At
present, its GDP accounts for 45% of the national total, and it brings together many innovative elements such as talents, capital, and technology. It has unique advantages and great development potential in the national economy. Its development plays a pivotal role, and the Yangtze River Economic Belt is an important area of growth in the national and regional economy. The core of regional development is collaborative innovation. The coordinated and stable development of regional innovation is conducive to promoting the development of the Yangtze River Economic Belt, facilitating the exploration of the huge potential domestic demand in the middle and upper reaches of its vast hinterland, and promoting economic growth via expansion from the coast to the inland stretches of the river, the formation of a complementary, collaborative, and interactive relationship between the upper, middle, and lower reaches, and narrowing the development gap between the eastern, central, and western regions; It is also conducive to optimizing the industrial structure and urbanization layout along the Yangtze River, building a new corridor for two-way communications between the inland and coastal areas, cultivating new advantages in international economic cooperation and competition, promoting economic and efficiency improvements, and helping to achieve the goals of the "two hundred years" struggle and the Chinese dream of the great rejuvenation of the nation. At present, the development of the Yangtze River Economic Belt faces many difficulties and problems that need to be solved urgently, for example, regional innovation and development are uncoordinated, there are difficulties in adapting to the new era and the rapidly changing external environment, and there is a gap between the Yangtze River Economic Belt and the world's leading innovation regions [3]. Studying the degree of synergy in the innovation system of the Yangtze River Economic Belt will help stimulate innovation activities in this region, enhance its core competitiveness, and promote its integration.

2. Literature review
From a systems perspective, innovation is not a single independent process but involves multiple subsystems that interact with each other. Synergy occurs in the innovation system between the subsystems that correspond to each component of the innovation process. The internal order parameters of each subsystem gradually evolve from a disorderly state to an orderly state and achieve synergy throughout the innovation activities. Domestic and foreign scholars have conducted different research studies on collaboration in the innovation system.

Firstly, research into regional innovation systems has mainly focused on their composition in terms of systems of production, education, and research. Fischer [4] and Cowan [5] studied regional collaborative innovation at the metropolitan level and pointed out that good synergy between the elements of innovation in the region, especially complementary knowledge, helps to enhance the innovation capability of a metropolitan area. Song and Zhao [6] believed that the main bodies involved in regional innovation are enterprises, universities, scientific research institutions, governments, and intermediary organizations. They analyzed the behaviors of innovation subjects in various provinces of China using principal component analysis and constructed a model of collaborative innovation for each province. Zhao [7] used the analytic hierarchy process to study the innovation activities of enterprises, universities, scientific research institutions, and governments and then used cluster analysis to analyze the performance of four innovative entities in 30 provincial-level regions of China, which were thus divided into three classes. Lu [8] used Meng’s composite system synergy model to divide regional innovation systems into innovation subjects, innovation factors, and innovation environments to select corresponding indicators for measuring and analyzing the order of synergistic innovation and the overall synergy between the subsystems in the Beijing-Tianjin-Hebei region. Dong and Zeng [9], on the basis of the theory of composite systems, used the composite system synergy model to construct a theoretical model of the composite innovation system in the information and communications industry, which they divided into the innovation environment subsystem, technological innovation subsystem, systems innovation subsystem, and industrial growth subsystem to analyze the synergy between its subsystems and the reasons why some parts were less synergistic. Yu and Yin [10] applied Meng’s composite system theory with respect to a provincial region as the
study area and divided the composite collaborative innovation system into the industrial subsystem, technological intermediary service subsystem, university subsystem, and scientific and technological institution subsystem, as well as analyzing it.

The second research area has comprised the evaluation of the innovation capability of the innovation system and related research on finance, technology, and industrial innovation. By empirical research on regional innovation capabilities, Cooke [11] found that research systems, technology transfer, and education systems have a greater impact on regional innovation capabilities, whereas innovation entities, socioeconomic environments, and innovation organizations have a greater impact on regional innovation governance. Research by Porter and Stern [12] shows that the most critical factor affecting a country's ability to innovate is the innovation environment and infrastructure. Riddle and Schwer [13] explored US technological innovation capabilities in terms of high-tech human capital, industrial R&D and investment, and knowledge stocks. Zabalaitu and Riagagotaij [14] used other two-dimensional indicators of innovative input and innovation in data envelopment analysis to measure the operational performance and innovation potential of the European regional innovation system. Pinto and Guerreiro [15] used factor analysis to measure the innovation capabilities of 175 regions in 15 European countries in terms of four dimensions: economic structure, the labor market, technological innovation, and human capital. Hemsiniemi [16] subdivided indicators of input and output from a national perspective and used situational analysis to classify each indicator and establish an index system for the evaluation of national innovation capability. Scholars such as Diamond [17], Boyd [18], and Dewatripont [19] adhered to a bank-led financial structure and believed that financial structures based on financial intermediaries such as banks can more effectively provide financial support for technological innovation activities of enterprises. Finance is the core of the modern economy, and the spatial spillover effect of the cross-regional coordinated development of financial markets helps to compensate for the unevenness of regional economic development and thus enhances the capability of regional industrial innovation and development [20]. Dai and Luo [21], from a theoretical analysis of the effect of technological innovation on financial development, concluded that technological progress can promote financial development. Therefore, policies should be transformed from supporting the industrial application of technological achievements to the construction of a financial environment that supports technological innovation. In recent years, scholars have carried out extensive research on the relationship between China's fiscal investment in technology and innovation by enterprises, which proves the necessity and promoting effect of fiscal investment in technology for industrial innovation. Sheng used an empirical test to draw the conclusion that the impact of fiscal investment in technology on high-tech industries follows an “inverted U-shaped” curve. Wang [22] combined the importance of the development of innovation in the national cultural industry and the supporting effect of technology on this industry with the actual situation to discuss the role of technology in the transmission of national culture, the realization of the value of the national cultural industry, and the supporting and promoting effects of technology on the development of innovation in the national cultural industry.

From the above analysis, it can be seen that in the evaluation of innovation capability the main methods of input and output have been analyzed. In research on regional collaborative innovation, both domestic and foreign studies are in the exploratory stage, and there is still no authoritative means of differentiation between innovation systems. Existing research has focused more closely on the relationship between industry–university–research cooperation, innovation subjects, innovation factors, innovation environments, and innovation and on financial innovation versus industrial and technological innovation and has not realized that finance, science and technology, and industry are all important components of the innovation system. Synergy between these three elements can better promote regional innovation. Therefore, on the basis of previous studies, this paper has continued to use Meng's [23] composite system synergy model to divide the innovation system into the financial subsystem, technological subsystem, industrial subsystem, and innovation investment. An indicator system for evaluation was established on the basis of two aspects of output, taking the Yangtze River Economic Belt as the research area and using panel data for the financial structure, technological
innovation, and industrial innovation of the Yangtze River Economic Belt for the period from 2011 to 2016 to analyze the internal subsystems of its innovation system and the degree of synergy between the various subsystems and measure the level of synergy in the innovation system in order to better promote collaborative innovation and development in the Yangtze River Economic Belt.

3. Construction of model of regional collaborative innovation and design of index system for evaluation

3.1. Model construction
In this study, the composite system synergy model [23], which is generally accepted by the academic community, was selected to measure the degree of synergy in the innovation system of the Yangtze River Economic Belt. Many interacting subsystems constitute the regional innovation system, and the degree of coordination among the subsystems in the composite system represents the element of coordination. In this paper, the term “synergy” refers to the degree of coordination between the subsystems in the regional collaborative innovation system of the Yangtze River Economic Zone and the level of synergy in the Yangtze River Economic Belt.

The collaborative innovation system \( S = \{S_1, S_2, \ldots, S_k\} \), was established, where \( S_j (j = 1, 2, \ldots, k) \) is the jth subsystem present in S, and \( S = \{S_{j_1}, S_{j_2}, \ldots, S_{j_k}\} \), \( S_j \) is in turn composed of "sub-subsystems" or several basic elements. In this paper, S refers to the total regional collaborative innovation system of the Yangtze River Economic Belt, and \( S_j \) refers to the sub-regional innovation systems of the 11 provinces in the Yangtze River Economic Belt. The mechanism of the composite synergy in S is formed by the mutual influence and cooperation of the individual values of \( S_j \).

For the regional innovation subsystem \( S_j (j \in [1, k]) \), the order parameter variable in its development process is defined as \( e_j = (e_{j_1}, e_{j_2}, \ldots, e_{j_n}) \), where \( n \geq 1 \), \( U_{ji} < e_{ji} < T_{ji} \), and \( i \in [1, n] \). If the value of \( e_{j_1}, e_{j_2}, \ldots, e_{j_n} \) is larger, the degree of order of the system is higher, the smaller this value is, the lower is the degree of order of the system; The larger is the value of \( e_{j_1}, e_{j_2}, \ldots, e_{j_n} \), the lower is the order of the system, the smaller this value is, the higher is the order of the system. Therefore, there are subordinate definitions as follows, The following formula defines the system order degree of the system \( U_j(e_{ji}) \) of the order parameter component \( e_{ji} \) of the system \( S_j \).

\[
U_j \left( e_{ji} \right) = \left\{ \begin{array}{ll}
\frac{e_{ji} - U_{ji}}{T_{ji} - U_{ji}}, & i \in [1, l_1] \\
\frac{T_{ji} - e_{ji}}{T_{ji} - U_{ji}}, & i \in [l_1 + 1, n]
\end{array} \right.
\]

(1)

It can be deduced from Equation (1) that \( U_j(e_{ji}) \in [0, 1] \), and the larger its the value is, the stronger is the order effect of \( e_{ji} \) on the regional innovation system. On the whole, the order of the innovation subsystem can be determined by the integration of \( U_j(e_{ji}) \). Theoretically, the overall effect on the regional innovation system depends not only on the magnitude of each order parameter, but also on the combination form of each order parameter. Different combinations result in different specific structures of the system, and the combination form determines the integration law by which the order degree is integrated, which is a geometric averaging method in this paper. Here \( U_j(e_{ji}) \) is the order degree of the order parameter variable \( e_{ji} \) of the regional innovation subsystem \( S_j \).
Equation (2) also shows that \( U_j(e_j) \in [0,1] \). If the value \( U_j(e_j) \) is greater, the higher is the order of the system, and vice versa. In the composite system synergy model of regional innovation, it is assuming that the composite system evolves from the initial time \( t_0 \) to the time \( t_1 \), and the order degree of the order parameters of each innovation system is \( U^0_j(e_j), j = 1,2,\ldots,k \), which represents the evolution process of the entire composite system. At time \( t_1 \) the system order degree of the order parameters of each subsystem is \( U^1_j(e_j), j = 1,2,\ldots,k \), and hence the overall innovation system in the time period from \( t_0 \) to \( t_1 \) is defined as a whole. The degree of synergy is:

\[
M = \theta \sum_{j} \gamma_j \left[ u^1_j(e_j) - u^0_j(e_j) \right] 
\]

(3)

\[
\theta = \frac{\min_j \left[ u^1_j(e_j) - u^0_j(e_j) \neq 0 \right]}{\min_j \left[ u^1_j(e_j) - u^0_j(e_j) \right] \neq 0}, \quad j = 1, 2, \ldots, k
\]

(4)

In this formula \( \gamma_j \geq 0, \sum_{i=1}^{n} \gamma_i = 1, i = 1, 2, \ldots, n \).

The overall degree of synergy in the composite regional innovation system is \( M \in [-1,1] \). If its value is larger, this indicates that the overall degree of synergy in the composite regional innovation system is higher, and vice versa. The effect of the parameter \( \theta \) is that the composite regional innovation system has a positive degree of synergy only if \( u^1_j(e_j) - u^0_j(e_j) > 0, \forall j \in [1,k] \). Under normal circumstances, if the order degree of one subsystem increases greatly, but the increase in the order of another subsystem is small or the order degree decreases, the whole system is in an unstable or uncoordinated state, which shows that \( M \in [-1,0] \). The characteristics and trends of the degree of synergy in the composite regional innovation system are mainly compared with those for the base period.

3.2. Design of indicator system for evaluation

In this paper, the collaborative innovation system of the Yangtze River Economic Belt consists of 11 provincial and municipal regional innovation subsystems, each of which has three corresponding order parameters, namely, finance, technology, and industry. In accordance with the actual development of the Yangtze River Economic Belt, this paper is based on the analysis of financial structures, technological innovation, and industrial innovation according to the general method for the evaluation of input and output, following the principles of scientific method, practicability, and operability. Via an analysis of the correlations between, and the discriminative power of, indicators, the method was gradually optimized, relevant indicators were screened, and appropriate secondary indicators (sub-elements) were constructed. The indicators were established as shown in Table 1.
Table 1. Index system for evaluation of collaboration development of regional finance/scientific and technological innovation/industrial innovation in the Yangtze River Economic Belt.

| Index                                                                 | Symbol | Unit          | Type |
|----------------------------------------------------------------------|--------|---------------|------|
| Deposit Balances of Banking and Financial Institutions                | X11    | Billion Yuan  | +    |
| Loan Balances of Banking and Financial Institutions                   | X12    | Billion Yuan  | +    |
| Financial Structure                                                   |        |               |      |
| Total Imports and Exports                                             | X13    | Billion Yuan  | +    |
| Stock Market Value                                                    | X14    | Billion Yuan  | +    |
| Subsystem                                                            |        |               |      |
| Number of Domestic Listed Companies                                   | X15    | Number        | +    |
| Insurance Penetration of Financial Sector, Insurance Devices          | X16    | Percentage    | +    |
| Per Capita GDP                                                        | X17    | Yuan          | +    |
| Scientific and (R&D) Staff                                           | X21    | Number        | +    |
| R&D Funding Intensity                                                 | X22    | Percentage    | +    |
| Technological Innovation                                              |        |               |      |
| Number of Domestic Patent Applications Accepted                       | X23    | Items         | +    |
| Number of Domestic Patent Applications                               | X24    | Items         | +    |
| Subsystem                                                            |        |               |      |
| Number of Scientific Papers Published by R&D Institutions             | X25    | Items         | +    |
| Technical Market Technology Export Regional Contracts                 | X26    | Ten Thousand Yuan | + |
| Technical Market Technology Transfer to Regional Contracts            | X27    | Ten Thousand Yuan | + |
| Industrial High-tech Industry R&D Personnel Full-time Equivalent      | X31    | Person-years  | +    |
| High-tech Industry Internal R&D Expenditure                           | X32    | Ten Thousand Yuan | + |
| High-tech Industry Patent Applications                                | X33    | Items         | +    |
| Subsystem                                                            |        |               |      |
| High-tech Industry Effective Invention Patents                        | X34    | Items         | +    |
| High-tech Industry R&D Projects                                      | X35    | Items         | +    |
| High-tech Industry New Product Development Projects                   | X36    | Items         | +    |
| High-tech Industry New Product Sales Revenue                          | X37    | Ten Thousand Yuan | + |

4. Measurement and evaluation using the composite system synergy model

According to the abovementioned construction of the financial structure–scientific and technological innovation–industrial innovation system, the orderliness of each subsystem and the overall synergy of the Yangtze River Economic Belt were analyzed. In this paper, data from 2011–2016 for the 11 provinces and cities in the Yangtze River Economic Belt were selected as a sample. The data were obtained from the China Science and Technology Statistical Yearbook and China High-tech Industry Statistical Yearbook for the relevant years and the statistical yearbooks of the various provinces and cities.

4.1. Measurement and analysis of the order degree of the regional subsystems

Because the measurement units used for the initial data were inconsistent, the original data were converted into a dimensionless format in order to ensure the accuracy of the results. After the data were standardized, Excel 2007 was used to calculate the order of each subsystem of the Yangtze River Economic Belt from 2011 to 2016. The abovementioned model was used to calculate the order parameters of each subsystem, as shown in Table 2.

According to the order parameters of each subsystem of the Yangtze River Economic Belt, the model was used to calculate the order degree of the financial–scientific and technological–industrial innovation system for each subsystem, and the geometric averaging method was used to integrate the order degree. The results are shown in Table 3, and the results of the integration process are shown in Figure 1.
Table 2. Order parameters of each subsystem of the Yangtze River Economic Belt.

| Order-parameter | Upper limit | Lower limit | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|-----------------|-------------|-------------|------|------|------|------|------|------|
| Shanghai        | Finance     | 7.00        | 0.00 | 6.18 | 6.03 | 5.98 | 5.90 | 6.28 | 6.12 |
|                 | Technology  | 7.00        | 0.00 | 4.73 | 4.41 | 4.36 | 4.27 | 3.99 | 3.89 |
|                 | Industry    | 7.00        | 0.00 | 2.37 | 2.04 | 1.96 | 1.99 | 1.92 | 1.78 |
| Jiangsu         | Finance     | 7.00        | 0.00 | 5.22 | 5.29 | 5.34 | 5.35 | 4.64 | 4.83 |
|                 | Technology  | 7.00        | 0.00 | 6.31 | 6.41 | 6.62 | 6.55 | 6.32 | 6.33 |
|                 | Industry    | 7.00        | 0.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| Zhejiang        | Finance     | 7.00        | 0.00 | 4.92 | 4.86 | 5.11 | 4.97 | 4.62 | 4.44 |
|                 | Technology  | 7.00        | 0.00 | 6.31 | 6.41 | 6.62 | 6.55 | 6.32 | 6.33 |
|                 | Industry    | 7.00        | 0.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| Anhui           | Finance     | 7.00        | 0.00 | 0.43 | 0.39 | 0.44 | 0.55 | 0.56 | 0.36 |
|                 | Technology  | 7.00        | 0.00 | 0.25 | 0.26 | 0.40 | 0.30 | 0.36 | 0.57 |
|                 | Industry    | 7.00        | 0.00 | 0.72 | 0.81 | 0.93 | 0.95 | 1.07 | 1.24 |
| Jiangxi         | Finance     | 7.00        | 0.00 | 1.54 | 1.46 | 1.38 | 1.61 | 1.34 | 1.32 |
|                 | Technology  | 7.00        | 0.00 | 1.89 | 2.02 | 2.42 | 2.82 | 2.96 | 3.08 |
|                 | Industry    | 7.00        | 0.00 | 1.19 | 1.19 | 1.20 | 1.21 | 1.23 | 1.25 |
| Hubei           | Finance     | 7.00        | 0.00 | 1.07 | 1.00 | 0.88 | 0.86 | 0.85 | 0.83 |
|                 | Technology  | 7.00        | 0.00 | 0.69 | 0.69 | 0.83 | 0.86 | 0.87 | 0.80 |
|                 | Industry    | 7.00        | 0.00 | 0.54 | 0.47 | 0.65 | 0.79 | 0.88 | 0.83 |
| Hunan           | Finance     | 7.00        | 0.00 | 1.17 | 0.91 | 1.18 | 1.19 | 0.96 | 0.89 |
|                 | Technology  | 7.00        | 0.00 | 0.77 | 0.96 | 0.87 | 0.97 | 0.80 | 1.41 |
|                 | Industry    | 7.00        | 0.00 | 0.34 | 0.28 | 0.32 | 0.44 | 0.58 | 0.60 |
| Chongqing       | Finance     | 7.00        | 0.00 | 2.41 | 2.19 | 2.33 | 2.27 | 2.27 | 2.22 |
|                 | Technology  | 7.00        | 0.00 | 1.65 | 1.77 | 2.14 | 2.13 | 2.16 | 2.33 |
|                 | Industry    | 7.00        | 0.00 | 1.66 | 1.61 | 1.75 | 1.79 | 1.32 | 1.39 |
| Sichuan         | Finance     | 7.00        | 0.00 | 0.12 | 0.11 | 0.11 | 0.08 | 0.04 | 0.08 |
|                 | Technology  | 7.00        | 0.00 | 0.05 | 0.01 | 0.02 | 0.16 | 0.12 | 0.10 |
|                 | Industry    | 7.00        | 0.00 | 0.17 | 0.21 | 0.26 | 0.25 | 0.18 | 0.16 |
| Guizhou         | Finance     | 7.00        | 0.00 | 0.64 | 0.57 | 0.65 | 0.63 | 0.55 | 0.44 |
|                 | Technology  | 7.00        | 0.00 | 0.34 | 0.46 | 0.37 | 0.41 | 0.47 | 0.48 |
|                 | Industry    | 7.00        | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
Table 3. Order degree of financial-technological-industrial innovation systems in various regions of the Yangtze River Economic Belt.

| Region   | Year | Degree of order       | Geometric mean | Region   | Year | Degree of order       | Geometric mean |
|----------|------|-----------------------|----------------|----------|------|-----------------------|----------------|
| Shanghai | 2011 | (0.88,0.68,0.34)      | 0.58           | Jiansu   | 2011 | (0.75,0.90,1.00)      | 0.88           |
|         | 2012 | (0.86,0.63,0.29)      | 0.54           |         | 2012 | (0.76,0.92,1.00)      | 0.89           |
|         | 2013 | (0.85,0.62,0.28)      | 0.53           |         | 2013 | (0.76,0.95,1.00)      | 0.90           |
|         | 2014 | (0.84,0.61,0.28)      | 0.52           |         | 2014 | (0.76,0.94,1.00)      | 0.89           |
|         | 2015 | (0.90,0.57,0.27)      | 0.52           |         | 2015 | (0.66,0.90,1.00)      | 0.84           |
|         | 2016 | (0.87,0.56,0.25)      | 0.50           |         | 2016 | (0.69,0.90,1.00)      | 0.85           |
| Zhejiang | 2011 | (0.70,0.43,0.50)      | 0.53           | Anhui   | 2011 | (0.19,0.17,0.10)      | 0.15           |
|         | 2012 | (0.69,0.49,0.50)      | 0.55           |         | 2012 | (0.17,0.19,0.12)      | 0.16           |
|         | 2013 | (0.73,0.47,0.52)      | 0.56           |         | 2013 | (0.16,0.22,0.13)      | 0.17           |
|         | 2014 | (0.71,0.49,0.49)      | 0.55           |         | 2014 | (0.16,0.24,0.14)      | 0.18           |
|         | 2015 | (0.66,0.49,0.57)      | 0.57           |         | 2015 | (0.17,0.23,0.15)      | 0.18           |
|         | 2016 | (0.63,0.54,0.56)      | 0.58           |         | 2016 | (0.16,0.24,0.18)      | 0.19           |
| Jiangxi  | 2011 | (0.06,0.04,0.04)      | 0.05           | Hubei   | 2011 | (0.22,0.27,0.17)      | 0.22           |
|         | 2012 | (0.06,0.04,0.04)      | 0.05           |         | 2012 | (0.21,0.29,0.17)      | 0.22           |
|         | 2013 | (0.06,0.06,0.06)      | 0.06           |         | 2013 | (0.20,0.35,0.17)      | 0.23           |
|         | 2014 | (0.08,0.04,0.06)      | 0.06           |         | 2014 | (0.23,0.40,0.17)      | 0.25           |
|         | 2015 | (0.08,0.05,0.06)      | 0.06           |         | 2015 | (0.19,0.42,0.18)      | 0.24           |
|         | 2016 | (0.05,0.08,0.07)      | 0.07           |         | 2016 | (0.19,0.44,0.18)      | 0.25           |
| Hunan   | 2011 | (0.15,0.10,0.08)      | 0.11           | Chongqing| 2011 | (0.17,0.11,0.05)      | 0.10           |
|         | 2012 | (0.14,0.10,0.07)      | 0.10           |         | 2012 | (0.13,0.14,0.04)      | 0.09           |
|         | 2013 | (0.13,0.12,0.09)      | 0.11           |         | 2013 | (0.17,0.12,0.05)      | 0.10           |
|         | 2014 | (0.12,0.12,0.11)      | 0.12           |         | 2014 | (0.17,0.14,0.06)      | 0.11           |
|         | 2015 | (0.12,0.12,0.13)      | 0.12           |         | 2015 | (0.14,0.11,0.08)      | 0.11           |
|         | 2016 | (0.12,0.11,0.12)      | 0.12           |         | 2016 | (0.13,0.20,0.09)      | 0.13           |
| Sichuan | 2011 | (0.34,0.24,0.24)      | 0.27           | Guizhou  | 2011 | (0.02,0.01,0.02)      | 0.02           |
|         | 2012 | (0.31,0.25,0.23)      | 0.26           |         | 2012 | (0.02,0.00,0.03)      | 0.00           |
|         | 2013 | (0.33,0.31,0.25)      | 0.29           |         | 2013 | (0.02,0.00,0.04)      | 0.00           |
|         | 2014 | (0.32,0.30,0.26)      | 0.29           |         | 2014 | (0.01,0.02,0.04)      | 0.02           |
|         | 2015 | (0.32,0.31,0.19)      | 0.27           |         | 2015 | (0.01,0.02,0.03)      | 0.02           |
|         | 2016 | (0.32,0.33,0.20)      | 0.28           |         | 2016 | (0.01,0.01,0.02)      | 0.01           |
| Yunnan  | 2011 | (0.09,0.05,0.00)      | 0.00           |         | 2011 | (0.09,0.05,0.00)      | 0.00           |
|         | 2012 | (0.08,0.07,0.00)      | 0.00           |         | 2012 | (0.08,0.07,0.00)      | 0.00           |
|         | 2013 | (0.09,0.05,0.00)      | 0.00           |         | 2013 | (0.09,0.06,0.00)      | 0.00           |
|         | 2014 | (0.08,0.07,0.00)      | 0.00           |         | 2014 | (0.08,0.07,0.00)      | 0.00           |
|         | 2015 | (0.08,0.07,0.00)      | 0.00           |         | 2015 | (0.06,0.07,0.00)      | 0.00           |
|         | 2016 | (0.06,0.07,0.00)      | 0.00           |         | 2016 | (0.06,0.07,0.00)      | 0.00           |
Figure 1. Order degree of subsystems in various regions of the Yangtze River Economic Belt.

(1) The order of the subsystems in the eastern (Shanghai, Zhejiang, and Jiangsu), central (Anhui, Jiangxi, Hubei, and Hunan), and western (Chongqing, Sichuan, Guizhou, and Yunnan) regions of the Yangtze River Economic Belt was analyzed. It can be seen from Figure 1 that the degree of coordination of the subsystems of the financial–technological–industrial innovation and development system in the Yangtze River Economic Belt was uneven from 2011 to 2016 and there were clear gaps between the eastern, central, and western regional subsystems, which were arranged in the order of East > Center > West. The main reasons for this may be differences in geographic conditions and transportation between the eastern, central, and western regions. The geology and geomorphology in the central and western regions are complex, natural disasters are frequent, and natural, ecological, climatic, and resource conditions vary widely. The eastern region has convenient transportation and a vast market. Many coastal cities and inland shipping hub cities have become trading ports and have undergone development earlier than inland cities. However, the Sichuan subsystem in the western region had a higher degree of order than all the central regional subsystems and was surpassed only by the eastern region, and the Chongqing subsystem in the western region surpassed the Hunan subsystem in the central region in 2016. This may have been due to the national policy of developing the western region and increasing the share of investment in the western region. The increase in various policies, coupled with the positive response of manpower, capital, and infrastructure in Chongqing and Sichuan and other internal factors, has led to increases in the efficiency of the corresponding policies and in the ratio of innovation to investment, which have made the order of the scientific, financial, and industrial innovation subsystems increase accordingly.

(2) In the eastern region, Jiangsu had the highest order, which reached 0.9 in 2013 and was on an upward trend from 2011 to 2013. Although it began to decline in 2014, the overall order was still the highest and increased again after 2015, which was mainly due to technological-industrial innovation capability. In terms of technological innovation, first of all Jiangsu has high-tech talents, and the number of R&D personnel was the highest among the 11 provinces and cities in the Yangtze River Economic Belt, namely, 455,135 in 2011 and 761,046 in 2016. Secondly, Jiangsu also ranked first in terms of patent applications, accepted patent applications, and technical contract transactions. In terms
of industrial innovation, full-time equivalent R&D personnel, and other indicators. Jiangsu also ranked first, whereas Shanghai and Zhejiang ranked second. The high ranking of Shanghai was mainly derived from its rich financial base, whereas Zhejiang is relatively strong in terms of industrial innovation and has better coordination. Shanghai had an order of 0.58 in 2011, but this declined to 0.50 in 2016, whereas the order of Zhejiang rose from 0.53 in 2011 to 0.58 in 2016; although there was a decline in 2014, the fluctuations were not very large, and the overall trend was upward. In the central region, the order of Hubei was relatively high and there were no large fluctuations, but the order of Jiangxi was not ideal. In the western region, Sichuan had the highest order, surpassed only by the eastern region, whereas Yunnan was the weakest as its average degree of order was basically zero, which was mainly due to its relatively weak industrial innovation capability. Judging from the orderly development of the subsystems in the Yangtze River Economic Belt, the degree of coordination of Jiangsu, Sichuan, and Guizhou is unstable and continues to fluctuate. The order of Shanghai has declined, whereas the development of other regions has been favorable.

4.2. Measurement and analysis of regional overall synergy

According to the different stages of the regional collaborative innovation system of the Yangtze River Economic Belt, 2011 was selected as the base period for calculating the overall degree of synergy in the regional collaborative innovation system of the Yangtze River Economic Belt, which was based on the weighting coefficients (Table 4) of each subsystem of the Yangtze River Economic Belt. When the weighting coefficients were calculated, the GDP index was used as the variable in the equation

$$\theta_i = \frac{\text{GDP}_i}{\sum_{i=1}^{11} \text{GDP}_i},$$

where $\theta_i$ is the weighting coefficient of the region $i$, where $i$ is represents Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Guizhou, or Yunnan. The calculated weighting coefficients are shown in Table 4. The overall synergy of the regional financial-technological-industrial collaborative innovation and development in the Yangtze River Economic Belt is shown in Figure 2.

| Year | Shanghai | Jiangsu | Zhejiang | Anhui | Jiangxi | Hubei | Hunan | Chongqing | Sichuan | Guizhou | Yunnan |
|------|----------|---------|----------|-------|---------|------|------|----------|--------|--------|-------|
| 2011 | 0.09     | 0.23    | 0.15     | 0.07  | 0.06    | 0.09 | 0.09 | 0.05     | 0.10   | 0.03   | 0.04  |
| 2012 | 0.09     | 0.23    | 0.15     | 0.07  | 0.05    | 0.09 | 0.09 | 0.05     | 0.10   | 0.03   | 0.04  |
| 2013 | 0.08     | 0.23    | 0.14     | 0.07  | 0.06    | 0.09 | 0.09 | 0.05     | 0.10   | 0.03   | 0.05  |
| 2014 | 0.08     | 0.23    | 0.14     | 0.07  | 0.06    | 0.10 | 0.09 | 0.05     | 0.10   | 0.03   | 0.05  |
| 2015 | 0.08     | 0.23    | 0.14     | 0.07  | 0.05    | 0.10 | 0.09 | 0.05     | 0.10   | 0.03   | 0.04  |
| 2016 | 0.08     | 0.23    | 0.14     | 0.07  | 0.05    | 0.10 | 0.09 | 0.05     | 0.10   | 0.03   | 0.04  |
Figure 2. Overall synergy of the regional financial-technological-industrial innovation system in the Yangtze River Economic Belt with 2011 as the base period.

(1) The results show that the overall degree of synergy in the financial–technological–industrial innovation system in the Yangtze River Economic Belt with 2011 as the base period was 0.0094, and the minimum value was −0.0024, i.e., negative synergy occurred, which was inconsistent with the overall trend. The level of synergy was unstable: the regional synergy was relatively stable and displayed an upward trend only between 2013 and 2014, whereas in other years the fluctuations were relatively large. (Because of the data processing method used in this paper, all the values are less than 1, and thus it may seem that the variations were not large. However, there were large fluctuations in reality.) The financial–technological–industrial innovation system in the Yangtze River Economic Belt is therefore not coordinated, and the coordinated development of the various subsystems still faces more problems.

(2) According to the composite system synergy model, in general, if the order degree of one subsystem increases greatly but that of another subsystem increases to a lesser extent or decreases, the whole system is in an unstable or uncoordinated state. The Yangtze River Economic Belt is not coordinated as a whole, and the gap between western and eastern China is large. The reason for this may firstly be related to the economy, in that a rich economic foundation can provide the impetus for industrial innovation and development, provide large-scale long-term investment financing for innovation systems, and promote the rational allocation of resources, but when the financial structure is weak, this seriously hinders technological–industrial innovation. A second reason is the differences in geographic conditions, as the geomorphology of the central and western regions is complex. For example, Yunnan is located on the southwestern frontier, which has seriously restricted its development, which is thus weak, and given rise to a large gap between Yunnan and highly developed cities. Secondly, natural disasters (such as earthquakes and debris flows) are frequent and hinder regional innovation. The geographic environment in the eastern region enables linkages between sea and land transportation, and transportation is convenient, which is conducive to flows of population and the like, helps communication, and promotes development. A third reason is related to innovation resources such as talents. The education level of the population in the western region is relatively poor in comparison with the eastern region, and the consequent lack of talents will inevitably lead to problems such as weak scientific and technological innovation. Because the discrepancy between
upstream, midstream, and downstream regions is so obvious, the integration of the Yangtze River Economic Belt still has a long way to go.

5. Conclusions and recommendations
Using the composite system synergy model, the development of the financial structure–scientific and technological innovation–industrial innovation system of the Yangtze River Economic Belt from 2011 to 2016 was measured. The results show that although the subsystems of the Yangtze River Economic Belt were in a more orderly state, the overall order was weaker, with a maximum value of only 0.0094. (If the value of the overall degree of synergy $M \in [-1,1]$ of the composite regional innovation system is larger, this indicates that the overall degree of synergy is higher; otherwise, the degree of synergy is lower.) In the Yangtze River Economic Belt in 2015, the overall financial–technological–industrial synergy was negative; that is, the system was in an uncoordinated state, which indicated that the state of coordination of financial–scientific–industrial innovation and development was unstable, and the effect of synergy was not obvious. The coordination of the 11 provinces and municipalities in the Yangtze River Economic Belt was unstable. Jiangxi, Zhejiang, Anhui, Chongqing, Hunan, and Hubei were basically in a state of steady increase, Jiangsu, Sichuan, and Guizhou continued to fluctuate, whereas Shanghai was in decline. The differences between the east and west of China were large. After analysis, these may be related to innovation factors such as geographic conditions, geographic environments, traffic conditions, economic conditions, and talents in the central, eastern, and western regions. On the basis of the current situation in terms of the difference in the level of coordinated development between the various subsystems in the Yangtze River Economic Belt and the low overall degree of synergy, the following are suggestions for the overall planning of the coordinated development of the Yangtze River Economic Belt:

(1) Financial aspects: We must make efforts to increase the growth of innovation in the regional economy, vigorously improve the potential of financial development, provide support for innovation and development, closely follow the principles of open development, and jointly foster new advantages in opening up. We must also strengthen strategic interactions with the “Belt and Road” and promote the formation of a new pattern of open development in the Yangtze River Economic Belt and the “Belt and Road.”

(2) Scientific and technological aspects: We must improve the resource-sharing mechanisms of regional scientific and technological innovation and at the same time exploit the capacity for diffusion of central cities. For example, Jiangsu's capability for scientific and technological development is outstanding, and it should therefore promote the diffusion of its innovation resources, which can be appropriately transferred to areas where technological innovation and development are weak to improve the basic innovation capability of these regions and enable financial–scientific–industrial collaborative innovation and development. Such a cooperation platform will better promote the coordinated development of the Yangtze River Economic Belt.

(3) Industrial aspects: We must attract high-level talents who meet the development needs of the Yangtze River Economic Belt and build core competitiveness according to the development status of the Yangtze River Economic Belt by cultivating and expanding emerging industries, attracting large-scale innovative enterprises to relocate, and jointly promoting the cooperation and interaction of industries along the Yangtze River. We must carry out "addition" by reform, innovation, and the development of new motive forces, as well as "subtraction" by eliminating backward overcapacity, accelerate the transformation and upgrading of industry, form a modern industrial corridor with high concentrations of enterprises and strong international competitiveness, and promote the synergistic development of the Yangtze River Economic Belt.

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