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Data-Driven Coupling Coordination Development of Regional Innovation EROB Composite System: An Integrated Model Perspective

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Abstract: To promote coupling coordination development for regional innovation environment-resource-output-benefit (EROB) composite systems, we propose a data-driven integrated model method for measurement, evaluation, and identification. First, we construct an evaluation indicator system of coupling coordination development of regional innovation EROB composite systems. Second, we apply the entropy method to measure indicator weights and comprehensive development indices of regional innovation composite systems. The coupling coordination degree model is used to calculate and evaluate four subsystems' coupling coordination development levels. The obstacle degree model is used to identify the main obstacle factors affecting coupling coordination development. Finally, using panel data of the Yangtze River Delta region (three provinces and one city) between 2014–2019 as a case study, we test the integrated model method. The results show that the comprehensive development level of the regional innovation EROB composite system in the Yangtze River Delta region maintained a stable growth trend; the coupling coordination development level among four subsystems continuously improved, with the main obstacle being the innovation resource subsystem. Accordingly, targeted policy suggestions are put forward. This study not only provides theoretical and methodological support for evaluating and optimizing regional innovation composite systems but also provides decision-making support for sustainable and high-quality development of regional economies.

Keywords: data-driven; regional innovation; integrated model; decision-making support

MSC: 90B50

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1. Introduction

Innovation is the power source of regional economic development [1]. Several studies have shown that innovation can generate significant increases in total factor productivity and economic aggregate. Every 1% increase in the stock of scientific and technological capital will lead to an increase in economic aggregate of 0.05–0.1 and a social return rate of approximately 20–50% [2]. At the beginning of the twentieth century, the contribution rate of science and technology to the growth of China's gross national product was 5–10%, 50% in the 1950s and 1960s, and 60–80% today. This shows that innovation is the primary driving force in leading development [3,4]. However, owing to historical, economic, and geographical factors, the unbalanced development of a regional innovation system (RIS) [5–7] is a major bottleneck restricting the improvement of comprehensive innovation ability in various countries. As the world's largest developing country, China relies on scientific and technological innovation to accelerate the transformation transition of the mode of economic development [8–10]. An RIS is an important part of a national innovation system [11] and plays a vital role in innovative country construction [12,13].

How to promote high-quality RIS development and realize the coupling and coordination of the innovation environment, resources, output, and benefits is key to the improvement of a region's overall innovation ability.

The term "regional innovation system", first proposed by Cooke [14] in 1989, is defined as the combination of various interacting institutions to provide an environment conducive to innovation activities in a particular region [15,16]. In recent years, many scholars [17–19] have paid attention to RISs. However, previous RIS research has mainly focused on elements such as influencing factors [20–22], structure [23,24], and evaluation [25,26]. In terms of influencing factors, Tang [27] explored the strategic role of world-class universities in an RIS and pointed out ways to increase the interaction among universities, governments, and industries. Zhang and Zhang [28] combed the influence of network factors and institutional factors on the development of RIS and its spatial spillover effect.

In terms of structure, Cooke [29] posited that any functioning RIS has two subsystems: knowledge application and mining and knowledge production and diffusion. Trippl and Tödtling [30] argued that an RIS comprises five core subsystems: knowledge creation and dissemination, knowledge application and development, regional policy, regional knowledge flow, and regional socioeconomics. Wei et al. [31] established that RISs are based on a knowledge management perspective from six aspects: knowledge base, knowledge creation, knowledge dissemination, knowledge sharing, knowledge application, and innovation environments. Yuan et al. [32] divided RISs into knowledge innovation, technological innovation, intermediary service, government supervision, innovation investment, and collaborative innovation systems, and used the grey fixed weight clustering method to evaluate and classify China's provincial innovation system. Dayneko et al. [33] posited that the key RIS components are technological, product, institutional, and ecological innovation, as well as innovation and entrepreneurship. Zhang et al. [34] divided RIS into innovation demand and innovation supply subsystems. Lewandowska and Švihlíková [35] constructed an RIS from five dimensions: population with tertiary education, R&D expenditure in the public sector, R&D expenditure in the business sector, EPO pattern applications, and employment in knowledge-intensive activities. Weck et al. [36] built an RIS framework based on knowledge collaboration, knowledge sharing, and knowledge management.

In the evaluation of RIS, the research has mainly included two aspects: construction of evaluation systems and selection of evaluation methods. Constructing an evaluation system mostly starts from the composition of an RIS. Zabala-Iturriagagoitia et al. [17] constructed an RIS evaluation index based on three aspects: innovation environment, innovation subject, and innovation performance. Some scholars [17,37] have also constructed RIS evaluation index systems from the three aspects of innovation resources, innovation output, and innovation environment. Zhao et al. [38] constructed an RIS evaluation index from the perspective of four innovation subjects—governments, universities, research institutions, and companies—and used an analytic hierarchy process (AHP) and cluster analysis to evaluate RISs in China. Wang and Zhang [39] constructed an index from green innovation environment, input, and output, and used a fuzzy AHP to evaluate the RIS innovation ability. Huang and Yang [40] constructed an evaluation index from the aspects of innovation input capacity, output capacity, diffusion, and environmental tolerance. Shan [41] selected several indicators from the aspects of input capacity, innovation environment, management capacity, and innovation output, and used AHP to evaluate an RIS. Polina and Solovyeva [42] evaluated the development level of a Russian RIS by using the index method—multiple average method—factor index analysis from three aspects: innovation climate, innovation potential, and innovation activities. Su et al. [43] constructed the evaluation index system of RIS from the four aspects of knowledge creation, knowledge acquisition, enterprise innovation, and innovation environment, and constructed a multi-attribute decision-making evaluation model to assess the regional innovation ability of 31 provinces in China. Lanchun et al. [44] constructed an evaluation index of county innovation systems based on innovation investment, innovation environment, enterprise innovation, and innovation performance. In addition, according to the operation mechanism of RIS, some scholars [45] have constructed the evaluation index of innovation systems with environment, strategy, operation, and structure as the main aspects. Yuan and Zheng [46] constructed an index system from innovation input, innovation cooperation, innovation output, and innovation auxiliary conditions, and applied improved intuitionistic fuzzy entropy for evaluation.

In terms of evaluation methods, various parametric and non-parametric methods have been introduced into input and output fields to evaluate RISs. Data envelopment analysis (DEA) [47] and stochastic frontier analysis (SFA) [48] have been the main methods used, as shown in Table 1. Zhao et al. [49] suggested using ordinal multidimensional scaling and cluster analysis as a robust method to study RISs. Further, some scholars [50,51] have used AHP to comprehensively evaluate RISs. Teng and Chen [52] conducted spatial measurement and evaluation of RIS performance based on neuropsychology. Su et al. [53] built a small world simulation model of an RIS to observe RIS knowledge flow. Zhang and Li [54] established an index system including technical, economic, and ecological benefits of innovation activities, and used the entropy method and fuzzy set qualitative comparison to measure the quality of RISs.

Table 1. Main evaluation methods of regional innovation systems.

Method	Research Object	References
RAGA-PP-SFA model	Manufacturing innovation system efficiency	Li al. [55]
Three-stage DEA-windows	China’s RIS efficiency	Qiao and Wang [56]
SFA	Italian’s RIS efficiency	Barra and Zotti [57]
Two-stage DEA model	Russian’s RIS performance	Rudskaya and Rodionov [58]; Jovanović et al. [59]
SBM model	RIS efficiency of Chinese provinces	Xu et al. [60]
DEA window technology	China’s RIS efficiency	Lv et al. [61]
Network DEA	Korea’s RIS efficiency	Um et al. [62]
Two-stage SBM-DNDEA model	Value creation process of China’s RIS	Lin et al. [63]

The research noted above provides an important foundation for the present study to explore the internal structure and relationship of RISs; however, some deficiencies remain. First, owing to different research perspectives and dimensions, there is still a lack of consensus on the structure and evaluation system of RISs from the perspective of an evaluation system. Under the goal of sustainable development, when constructing an evaluation system, it is necessary to consider not only the innovation output but also the social, economic, and environmental benefits derived from innovation. Second, the existing evaluation methods and tools only measure the development level and efficiency of an overall RIS. Its essence is to regard an RIS as a “black box” system, which cannot describe the innovation differences within the region or the interaction, coupling, and coordination among the subsystems within the RIS. Third, when selecting existing evaluation indicators, subjective deviation in the quantification of qualitative indicators is inevitable. Among existing evaluation methods, there is inevitably a qualitative evaluation method using experience and knowledge, which can easily lead to fuzziness in the evaluation results.

Therefore, it is necessary to build a data-driven evaluation system and evaluation model to ensure the objectivity and persuasiveness of evaluation results. To meet the above challenges, this study proposes an integrated model method based on a data-driven coupling coordination development of regional innovation environment-resource-output-benefit (EROB) composite system and conducts a quantitative measurement, evaluation, and identification to quantitatively characterize the coupling and coordination relationship and dynamic evolution of various subsystems within an RIS, to provide more accurate positioning in RIS cultivation.

The remainder of this article is organized as follows. Section 2 primarily describes the method flow of data-driven data acquisition, data processing, data modeling, and data application. Section 3 presents a case study, which tests the method and puts forward targeted countermeasures and suggestions. Section 4 is the conclusion.

2. Method

This section comprehensively introduces the measurement, evaluation, and identification methods of the coupling coordination development of a regional innovation EROB composite system, including method flow and data acquisition, processing, modeling, and application.

2.1. Method Flow

To promote sustainable RIS development, it is necessary to construct a measurement framework and evaluation system for internal coupling coordination development of RIS from the perspective of system theory, and conduct the first trial of systematic, holistic, and collaborative reform from the perspective of global optimization, which is an urgent need for the internal coupling coordination development of RIS. However, when facing the complexity and diversity of RIS data indicators, research challenges emerge in determining how to use effective methods to measure, evaluate, identify, and optimize the internal coupling coordination development of RIS.

To meet these challenges and improve the development level of RIS, this study constructed a measurement, evaluation, identification, and optimization method of coupled and coordinated development of a regional innovation EROB composite system based on data. Data collection was mainly performed to gather relevant data on aspects such as the regional innovation environment, resources, output, and benefits. Data processing was used to calculate the index weight and comprehensive development coefficient using the entropy method. Data modeling was performed to build a CCDM to measure the coupling and coupling coordination degrees and use the obstacle degree model to identify the key obstacles affecting development. Innovation practice was employed to apply the constructed method to the Yangtze River Delta (YRD) region (three provinces and one city), verify the model, obtain evaluation results, and put forward policy suggestions to promote the development of a regional innovation EROP composite system. A flowchart of the study's method is shown in Figure 1.

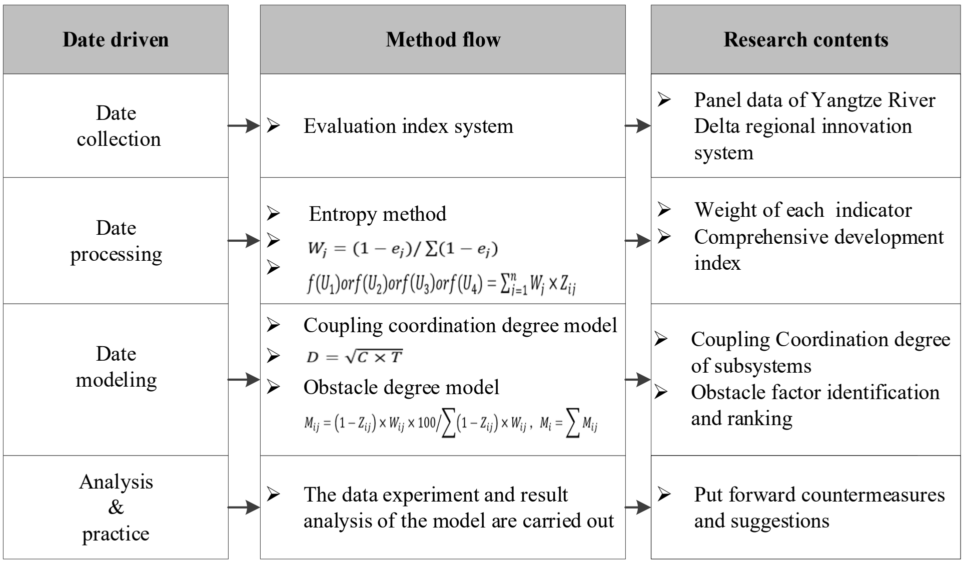


Figure 1. Study method flowchart.

2.2. Data Collection

The evaluation index is the key factor in measuring the coupling coordination development of a regional innovation EROB composite system. According to the principles of scientificity, hierarchy, systematicness, representativeness, and availability, this study referred to the research of relevant scholars, integrated the characteristics of RIS, and constructed an index system of the coupling and coordination relationship of a regional innovation EROB composite system (Table 2). The index system includes four subsystems: innovation environment [64], innovation resources, innovation output, and innovation benefits [63].

Innovation is strongly dependent on the environment. The innovation environment subsystem draws lessons from the Research Report on the evaluation of China's urban innovation and entrepreneurship environment and selects the cultural environment (C1) [65,66] and economic environment (C2) [67]. The cultural environment provides a good cultural atmosphere for regional innovation. Therefore, this paper selects three indexes to evaluate the cultural environment, including the number of legal entities in cultural and related industries above the designated size (C11), number of public library institutions (C12), and public library collection per unit population (C13). The economic environment reflects the strength of innovation support. Total investment in fixed assets (C21), financial revenue (C22), and actual utilized foreign capital (C23) are selected as the economic environment measurement indicators.

The innovation resource subsystem mainly reflects the resources consumed by innovation; these are primarily financial resources (C3) and human resources (C4) [68]. Human resources reflect the subjective initiative of innovation, and financial resources are the objective reflection of innovation investment. In this paper, the financial resource investment intensity is represented by three indicators: internal expenditure of R&D funds (C31), R&D expenditure intensity (C32), and local financial expenditure on education (C33). Three indicators are selected to express the intensity of human resources investment, namely, the number of students in colleges and universities per 100,000 population (C41), R&D personnel full-time equivalent (C42), and R&D personnel input (C43).

The innovation output subsystem directly reflects the operation results of the innovation system, which should include not only knowledge creation (C6) [69,70] but also economic output (C5). Economic output (C5) represents the scientific and technological achievements put into practice to generate economic value. This paper selects sales revenue of new products of industrial enterprises above the designated size (C51), technology market turnover (C52), and sales revenue of new products in high-tech industries (C53) to reflect the economic output capacity. Knowledge creation is mainly represented by scientific papers and patents. This paper selects three indicators to evaluate the ability of knowledge creation: the number of published scientific papers (C61), invention patent authorization (C62), and patent application authorization (C63).

The innovation benefit subsystem can directly reflect the promotion of innovation for high-quality development of the regional economy and society. The purpose of innovation is to create value. This paper pays attention to the unity of environmental benefit (C7), social benefit (C8), and economic benefit (C9) [71]. Environmental benefit (C7) is the effect and benefit of innovation on natural ecology. In this paper, three indicators are selected to reflect the environmental benefits, namely, the total industrial wastewater discharge (C71), the total industrial sulfur dioxide emission (C72), and industrial smoke (powder) dust emission (C73). Social benefit (C8) is the contribution made to society after the implementation of innovation, also known as an external indirect economic benefit. This paper selects four indexes to reflect social benefits: urban registered unemployment rate (C81), the Engel coefficient of urban households (C82), traffic accident fatalities (C83), and the per capita disposable income of urban residents (C84). Economic benefit (C9) is the effect and benefit of the return on investment. This paper selects three indexes to reflect the economic benefits: the total retail sales of social consumer goods (C91), per capita GDP (C92), and the proportion of the added value of the tertiary industry in GDP (C93).

To sum up, this paper constructs an evaluation index system of coupling coordination development of regional innovation EROB composite system with four subsystems, eight primary indexes, and 28 secondary indexes, and reviews the literature on the rationality behind the selection of each index. As shown in Table 2.

Table 2. Evaluation index system of coupling coordination development of regional innovation EROB composite system.

Subsystem	Primary Index	Secondary Index	Unit	Direction	References
Innovation environmentU1	Cultural environment C1	Number of legal entities in cultural and related industries above designated sizeC11	unit	+	[38]
		Number of public library institutions C12	unit	+	[41,42]
		Public library collection per unit population C13	piece	+	[42]
	Economic environment C2	Total investment in fixed assets C21	100 million RMB		[37,42]
		Financial revenue C22	100 million RMB	+	[38,58]
		Actual utilized foreign capital C23	100 million RMB		[38,43]
Innovation resourceU2	Financial resource C3	Internal expenditure of R&D funds C31	million RMB	+	[41,43]
		R&D expenditure intensity C32	%	+	[41,42]
		Local financial expenditure on education C33	100 million RMB	+	[41,43]
	Human resource C4	Number of students in colleges and universities per 100,000 population C41	person	+	[38]
		R&D personnel full-time equivalent C42	person year	+	[41,43,53]
		R&D personnel input C43	person	+	[39,41]
Innovation output U3	Economic output C5	Sales revenue of new products of Industrial Enterprises above Designated Size C51	million RMB	+	[43,44,53]
		Technology market turnover C52	million RMB	+	[39,43,53]
		Sales revenue of new products in high-tech industries C53	million RMB	+	[38,43]
	Knowledge creation C6	Number of published scientific papers C61	piece	+	[38,39,43]
		Invention patent authorization C62	piece	+	[37,43,53]
		Patent application authorization C63	piece	+	[37,39,43]
Innovation benefit U4	Environmental benefit C7	Total industrial wastewater discharge C71	10,000 tons	–	[43,53,63]
		Total industrial sulfur dioxide emission C72	10,000 tons	–	[33,43,53]
		Industrial smoke (powder) dust emission C73	10,000 tons	–	[43,53]
	Social benefit C8	Urban registered unemployment rate C81	%	–	[43,71]
		Engel coefficient of urban households C82	%	–	[43,71]
		Traffic accident fatalities C83	person	–	[43,71]
		Per capita disposable income of urban residents C84	RMB	+	[38,44]
	Economic benefit C9	Total retail sales of social consumer goods c91	million RMB	+	[63,71]
		Per capita GDP C92	RMB/person	+	[17,41,44]
		Proportion of added value of tertiary industry in GDP C93	%	+	[63,71]

2.3. Data Processing

The common evaluation index weighting methods involve subjective weighting and objective weighting methods. In the subjective weighting method, AHP has been widely used for practical application because it hierarchizes complex problems and quantifies qualitative problems. The objective weighting method examines the correlation between indicators according to objective data, and the weighting coefficient has strong objectivity. Common objective weighting methods include the entropy method [72], principal component analysis method [73], and anti-entropy weight method [74]. The entropy method is an objective weight determination method [75]. The greater its value, the greater the amount of information provided by the index, and the higher the weight of the corresponding index. In view of the wide application of the entropy method [76,77], this method was used for data processing in the present study. The specific steps for calculation when using the entropy method are as follows:

Step 1: considering the inconsistency of the nature and dimension of each index, the data range standardization method is adopted to standardize the range of positive index and negative index respectively. The equations are as follows:

$$\text{Positive index}: \ Z_{ij} = \frac{X_{ij} - X_{jmin}}{X_{jmax} - X_{jmin}} \tag{1}$$

$$\text{Negative index}: \ Z_{ij} = \frac{X_{jmax} - X_{ij}}{X_{jmax} - X_{jmin}} \tag{2}$$

X_{ij} is the value of index j in sample i, and X_{jmin} and X_{jmax} are the minimum and maximum values of index j in sample i, respectively. Z_{ij} represents the dimensionless value.

Step 2: calculate the proportion of index j in sample i:

$$P_{ij} = \frac{Z_{ij}}{\sum_{i=1}^{m} Z_{ij}} i = 1,2,3,\ldots,\text{m}; j = 1,2,3,\ldots,\text{n} \tag{3}$$

Step 3: calculate the information entropy of index j:

$$e_j = -1/\ln m \sum_{i=1}^{m} P_{ij} \ln P_{ij} \ \ i = 1,2,3,\ldots,\text{m}; j = 1,2,3,\ldots,\text{n} \tag{4}$$

where m is the number of years, $0 \leq e_j \leq 1$.

Step 4: calculate the weight of index j:

$$W_j = (1 - e_j) / \sum_{j=1}^{n} (1 - e_j) \ \ j = 1,2,3,\ldots,\text{n} \tag{5}$$

Step 5: calculate the development coefficient of each subsystem in sample i:

$$f(U_1) or f(U_2) or f(U_3) or f(U_4) = \sum_{j=1}^{n} W_j \times Z_{ij} \ \ i = 1,2,3,\ldots,\text{m}; j = 1,2,3,\ldots,\text{n} \tag{6}$$

where, $f(U_1)$, $f(U_2)$, $f(U_3)$, and $f(U_4)$ are the comprehensive evaluation values of the innovation environment, innovation resource, innovation output, and innovation benefit subsystems, respectively (i.e., the development coefficient).

2.4. Data Modeling

2.4.1. Coupling Coordination Degree Model

A CCDM can be used to measure the degree of interaction between systems or among various elements within a system [78]. The degree of coupling and coordination determines the development state of the system [79,80]. In recent years, this model has often been used in cases with two subsystems [81,82] or three subsystems [83]. Wang et al. [84] and Tonghui and Junfei [85] have provided detailed evidence of a multi-subsystem coupling formula. This study constructed a CCDM among the four subsystems of regional innovation environment, innovation resources, innovation output, and innovation benefits. Referring to relevant previous research [81,86], the equation for the coupling degree is as follows:

$$C = 4 \cdot \left[\frac{f(U_1) \cdot f(U_2) \cdot f(U_3) \cdot f(U_4)}{(f(U_1) + f(U_2) + f(U_3) + f(U_4))^4} \right]^{\frac{1}{4}} \tag{7}$$

where, C is the coupling degree of the four subsystems, and the value of C is in the interval [0, 1]. The closer the C value is to 1, the better the coupling state between systems. When the value of C is equal to 1, the coupling state is optimal. Further, $f(U_1)$ is the comprehensive development coefficient of the innovation environment subsystem, $f(U_2)$

is the comprehensive development coefficient of the innovation resource subsystem, $f(U_3)$ is the comprehensive development coefficient of the innovation output subsystem, and $f(U_4)$ is the comprehensive development coefficient of the innovation benefit subsystem.

Based on the results from calculating the coupling degree, the coupling coordination development degree between subsystems of the regional innovation EROB composite system was further calculated. The equation is as follows:

$$T = af(U_1) + bf(U_2) + cf(U_3) + df(U_4),\ D = \sqrt{C \times T} \tag{8}$$

T is the comprehensive development coefficient of the four subsystems, and a, b, c, d are the regulation coefficients. Some scholars [34–36] pointed out that the innovation environment, innovation resource, innovation output, and innovation benefit are equally important to the development of RISs, so we let $a = b = c = d = 0.25$. D is the coupling coordination scheduling, which indicates the coupling coordination development degree of the four subsystems, and the value is within the interval [0, 1]. Combining formulas (7) and (8), we derive a simpler and more direct formula for calculating D:

$$D = [f(U_1) \cdot f(U_2) \cdot f(U_3) \cdot f(U_4)]^{\frac{1}{8}} \tag{9}$$

Referring to relevant research [78,87] on coupling coordination evaluation, we set the evaluation criteria and basic types of coupling degree and coupling coordination degree as is shown in Table 3.

Table 3. Classification criteria of coupling degree and coupling coordination degree.

C Value Range	C Value Type	D Value Range	D Value Type
[0, 0.3]	Low-level coupling stage	[0, 0.1]	Extreme Disorder
		(0.1, 0.2]	Serious Disorder
		(0.2, 0.3]	Moderate Disorder
(0.3, 0.5]	Confrontation stage	(0.3, 0.4]	Mild Disorder
		(0.4, 0.5]	On the Verge of Disorder
(0.5, 0.8]	Running in stage	(0.5, 0.6]	Barely Coordinated
		(0.6, 0.7]	Primary Coordination
		(0.7, 0.8]	Intermediate Coordination
(0.8, 1]	High-level coupling stage	(0.8, 0.9]	Good Coordination
		(0.9, 1]	High-quality Coordination

2.4.2. Obstacle Degree Model

The purpose of an obstacle degree model is to diagnose the obstacle factors affecting the coupling coordination development of a regional innovation EROB composite system [88]. Based on the analysis of obstacle factors, it is conducive for the government to formulate and adjust coordinated development policies and measures of the regional innovation EROB composite system. The equation is as follows:

$$M_{ij} = \left(1 - Z_{ij}\right) \times W_j \times 100 / \textstyle\sum_{i=1}^{m} \left(1 - Z_{ij}\right) \times W_j, M_i = \textstyle\sum_{j=1}^{n} M_{ij} \tag{10}$$

where $i = 1, 2, 3, \ldots, \mathrm{m}; j = 1, 2, 3, \ldots, \mathrm{n}$. M_{ij} is the obstacle degree of secondary index j in primary index i to the coupling and coordination relationship of regional innovation EROB composite system. M_i represents the obstacle degree of primary index i. Z_{ij} represents the standardized value of the secondary index j obtained by the range standardization method, $1 - Z_{ij}$ indicates the deviation degree of the index. W_j is the weight of index j.

2.5. Data Application

The purpose of this study was to measure, evaluate, and identify the coupling coordination development and obstacle degree of a regional innovation EROB composite system using a data-driven method, and then put forward targeted optimization suggestions. This study can provide a basis for decision-making related to the sustainable development of regional innovation EROB composite systems. Figure 2 shows the specific data application.

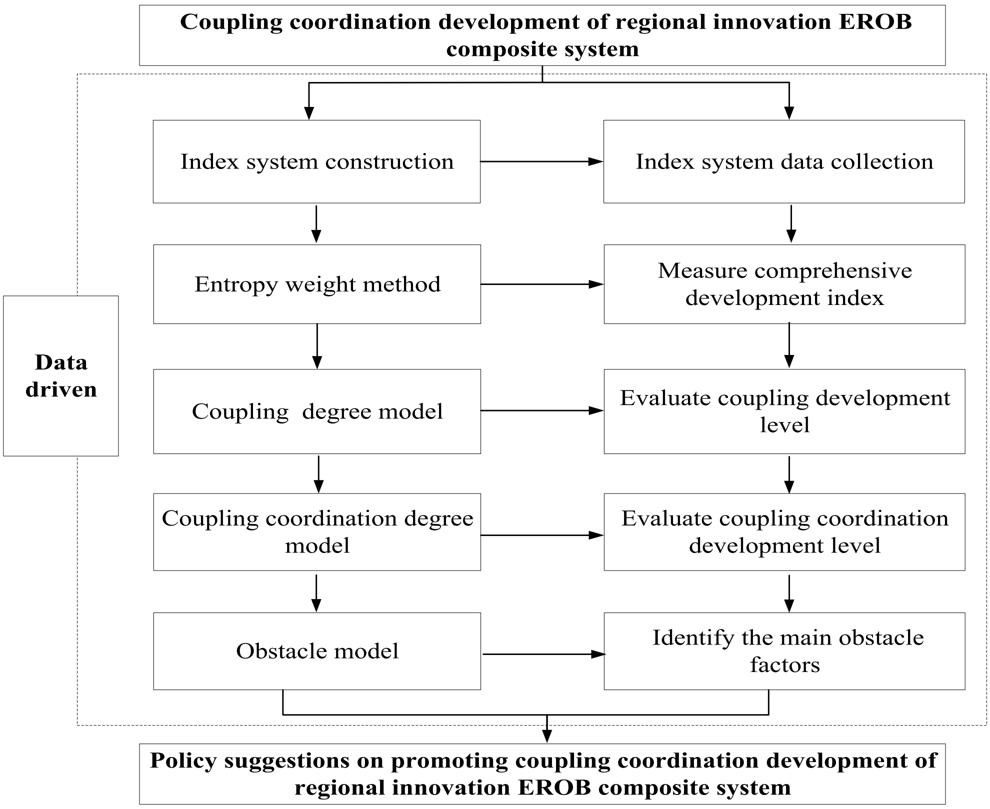


Figure 2. Data application diagram.

The first step was to construct the evaluation index system of coupled and coordinated development of a regional innovation EROB composite system from the four dimensions of innovation environment, resources, output, and efficiency. The entropy method was used to calculate the comprehensive development coefficient of the regional innovation EROB composite system. The second step was to build the coupling degree model, CCDM, and obstacle degree model to measure, evaluate, and identify the coupling and coordination degree of the regional innovation EROB composite system. The third step was to analyze the comprehensive development level of the regional innovation EROB composite system, according to the measurement results of the comprehensive development coefficient. Based on the evaluation results of the coupling and coordination degree of the regional innovation EROB composite system, the coupling and coordination development levels among the subsystems in the composite system were analyzed. Based on the main obstacle factors that restrict the coupling coordination development of the regional innovation EROB composite system, the shortcomings of regional innovation development were supplemented, and policy suggestions were put forward.

3. Case Study

To illustrate the effectiveness and feasibility of the method described in Section 2, we used the YRD region as the research object to verify the method. To ensure the authority and reliability of basic index data collection, relevant data on RIS development between 2014–2019 were selected, including the statistical years from provinces and cities, from the

China Statistical Yearbook, China Science and Technology Statistical Yearbook, and China Environmental Statistical Yearbook. The type of data used was panel data.

3.1. Background

The YRD region is among the regions with the most active economic development, the highest degree of openness, and the strongest innovation ability worldwide [89]. Today, the YRD region (Figure 3) includes three provinces (Jiangsu, Zhejiang, and Anhui) and one city (Shanghai). The regional area is 358,000 km^2, with a permanent resident population of more than 200 million. The regional GDP accounts for about one-quarter of the national total. The coordinated economic, ecological, energy, urban, and industrial development in the YRD region has been widely studied [90–92]; however, less research has been conducted on the area's coordinated RIS development. Under the national innovation-driven development and regional coordinated development strategies, this area may show significant regional differences and city differences in the coupling coordination development of RIS, which may affect its high-quality development. Therefore, this study constructed a regional innovation EROB composite system, and evaluated, measured, identified, and optimized the coupling coordination development of this composite system, to promote high-quality RIS development in the YRD region.

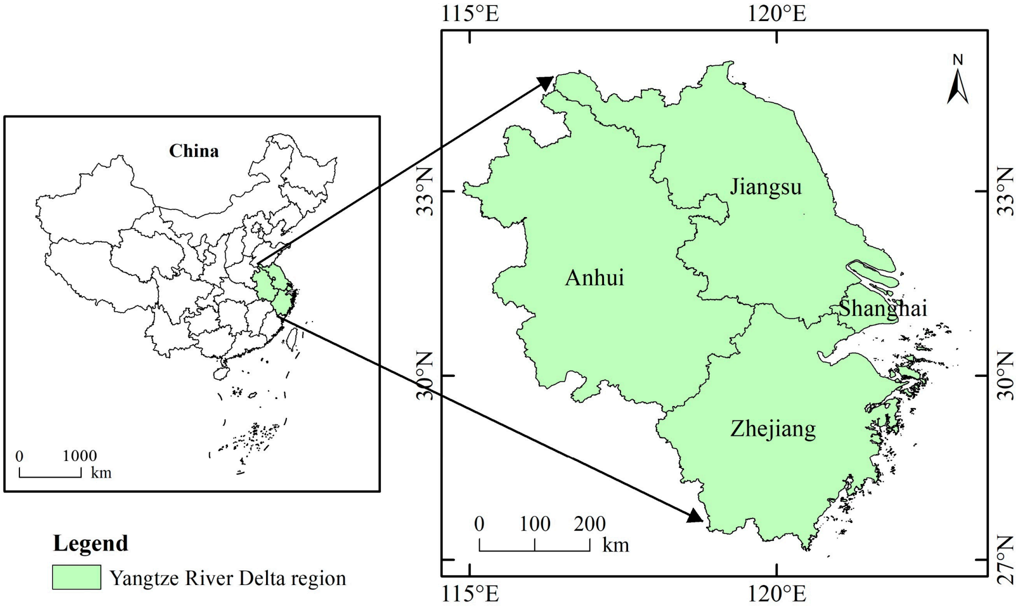


Figure 3. Case study area.

3.2. Results

3.2.1. Calculation Results of the Development and Comprehensive Development Indices

According to the above evaluation index system, the development and comprehensive development indices of each subsystem in the YRD region between 2014–2019 were calculated using Equations (1)–(6) of the entropy method, as shown in Table 4 and Figure 4.

Table 4. Development and comprehensive development indices of the innovation subsystem.

Year	Region	U	U1	U2	U3	U4
2014	Anhui	0.1122	0.1932	0.0044	0.0396	0.2298
	Zhenjiang	0.3094	0.4311	0.2673	0.2452	0.3147
	Jiangsu	0.5133	0.6632	0.5654	0.5917	0.2575
	Shanghai	0.3962	0.4982	0.3097	0.2034	0.5888
	Yangtze River Delta	0.3328	0.4464	0.2867	0.2700	0.3477

Table 4. *Cont*.

Year	Region	U	U1	U2	U3	U4
2015	Anhui	0.1421	0.2091	0.0327	0.0791	0.2640
	Zhenjiang	0.3555	0.3899	0.3220	0.3422	0.3756
	Jiangsu	0.5575	0.6083	0.6150	0.7106	0.3068
	Shanghai	0.3865	0.3460	0.3248	0.2364	0.6304
	Yangtze River Delta	0.3604	0.3883	0.3236	0.3421	0.3942
2016	Anhui	0.1760	0.2464	0.0351	0.1052	0.3365
	Zhenjiang	0.4004	0.4319	0.3394	0.3881	0.4514
	Jiangsu	0.6216	0.6572	0.6746	0.7724	0.3904
	Shanghai	0.4215	0.3671	0.3471	0.2695	0.6922
	Yangtze River Delta	0.4049	0.4256	0.3491	0.3838	0.4676
2017	Anhui	0.2050	0.2736	0.0605	0.1204	0.3838
	Zhenjiang	0.4404	0.4600	0.3794	0.4117	0.5171
	Jiangsu	0.6651	0.6920	0.7205	0.7939	0.4598
	Shanghai	0.4574	0.3827	0.3943	0.2973	0.7409
	Yangtze River Delta	0.4420	0.4521	0.3887	0.4058	0.5254
2018	Anhui	0.2321	0.2937	0.0774	0.1676	0.4087
	Zhejiang	0.5111	0.4929	0.4542	0.5391	0.5604
	Jiangsu	0.7170	0.7065	0.7700	0.8926	0.5005
	Shanghai	0.5009	0.3887	0.4202	0.3846	0.7925
	Yangtze River Delta	0.4903	0.4704	0.4304	0.4960	0.5655
2019	Anhui	0.2871	0.3862	0.1499	0.1871	0.4474
	Zhenjiang	0.5722	0.5014	0.5710	0.6167	0.5898
	Jiangsu	0.7839	0.7231	0.8904	0.9712	0.5408
	Shanghai	0.5445	0.4324	0.4694	0.4451	0.8136
	Yangtze River Delta	0.5469	0.5108	0.5202	0.5550	0.5979

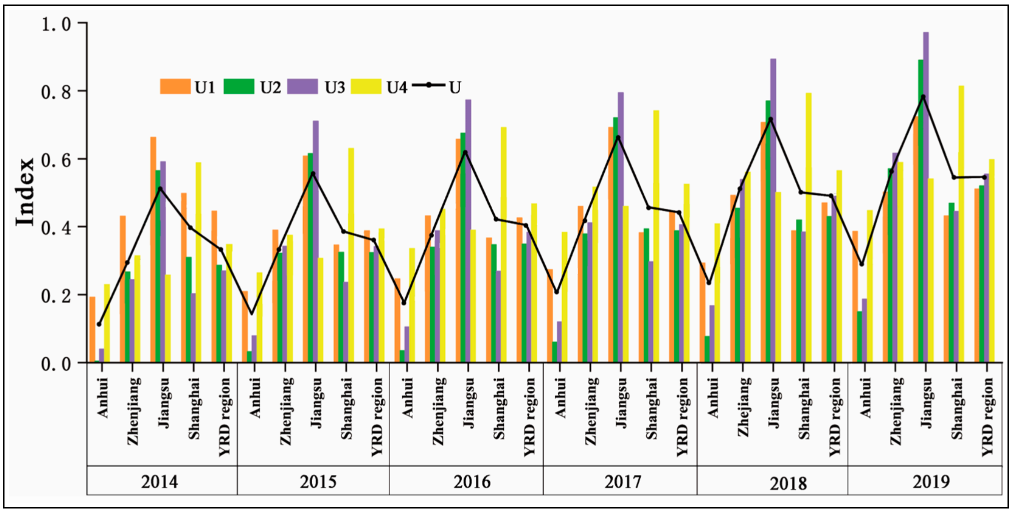


Figure 4. Development index and comprehensive development coefficient of the innovation subsystem.

3.2.2. Coupling Coordination Degree Calculation Results

The coupling and coordination degree model was used to calculate the coupling and coordination degree of four subsystems in the YRD region and three provinces and one city-regional innovation EROB composite system between 2014–2019. Table 5 shows the specific results. The evolution trends of coupling degree and coupling coordination degree are shown in Figures 5 and 6.

Table 5. Coupling degree and coordination degree of the regional innovation EROB composite system in the YRD region.

Year	Region	C	T	D	Status
2014	Anhui	0.4506	0.1168	0.2294	Moderate Disorder
	Zhenjiang	0.9762	0.3146	0.5542	Barely Coordinated
	Jiangsu	0.9412	0.5195	0.6992	Primary Coordinated
	Shanghai	0.9217	0.4000	0.6072	Primary Coordinated
	Yangtze River Delta	0.8224	0.3377	0.5225	Barely Coordinated
2015	Anhui	0.7475	0.1462	0.3306	Mild Disorder
	Zhenjiang	0.9972	0.3574	0.5970	Barely Coordinated
	Jiangsu	0.9540	0.5601	0.7310	Intermediate Coordination
	Shanghai	0.9358	0.3844	0.5998	Barely Coordinated
	Yangtze River Delta	0.9086	0.3621	0.5646	Barely Coordinated
2016	Anhui	0.7315	0.1808	0.3637	Mild Disorder
	Zhenjiang	0.9941	0.4027	0.6327	Primary Coordination
	Jiangsu	0.9696	0.6237	0.7776	Intermediate Coordination
	Shanghai	0.9372	0.4190	0.6266	Primary Coordination
	Yangtze River Delta	0.9081	0.4065	0.6001	Primary Coordination
2017	Anhui	0.7935	0.2096	0.4078	On the Verge of Disorder
	Zhenjiang	0.9932	0.4420	0.6626	Primary Coordination
	Jiangsu	0.9799	0.6666	0.8082	Good Coordination
	Shanghai	0.9409	0.4538	0.6534	Primary Coordination
	Yangtze River Delta	0.9269	0.4430	0.6330	Primary Coordination
2018	Anhui	0.8386	0.2368	0.4457	On the Verge of Disorder
	Zhenjiang	0.9967	0.5116	0.7141	Intermediate Coordination
	Jiangsu	0.9787	0.7174	0.8379	Good Coordination
	Shanghai	0.9514	0.4965	0.6873	Primary Coordination
	Yangtze River Delta	0.9414	0.4906	0.6712	Primary Coordination
2019	Anhui	0.9016	0.2926	0.5137	Barely Coordinated
	Zhenjiang	0.9971	0.5697	0.7537	Intermediate Coordination
	Jiangsu	0.9759	0.7814	0.8733	Good Coordination
	Shanghai	0.9640	0.5401	0.7216	Intermediate Coordination
	Yangtze River Delta	0.9596	0.5460	0.7155	Intermediate Coordination

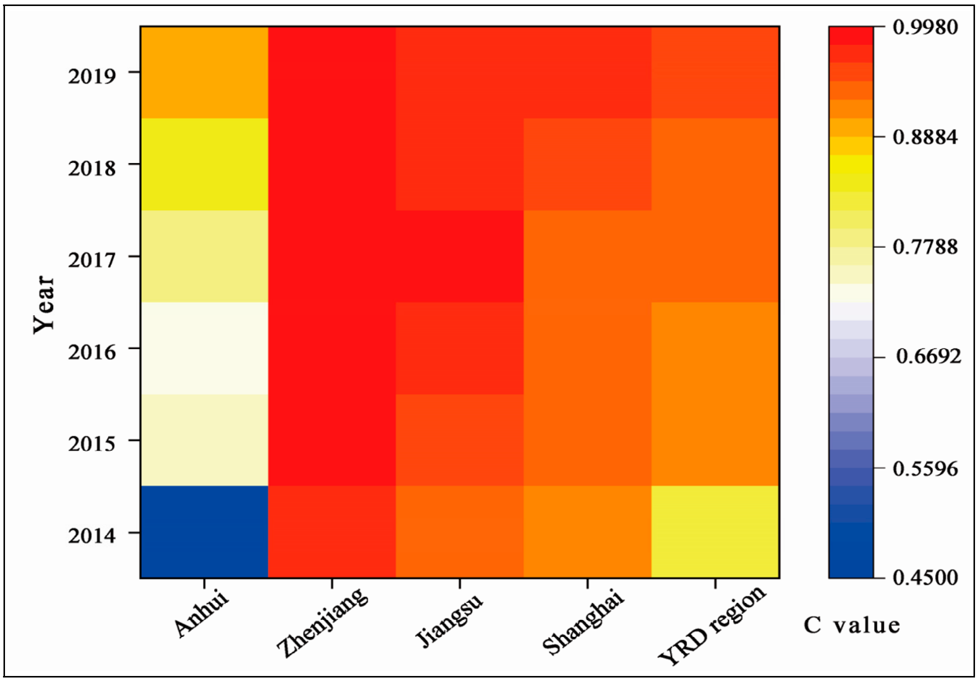


Figure 5. Evolution trends of coupling degree of innovation in the EROB composite system in the YRD region.

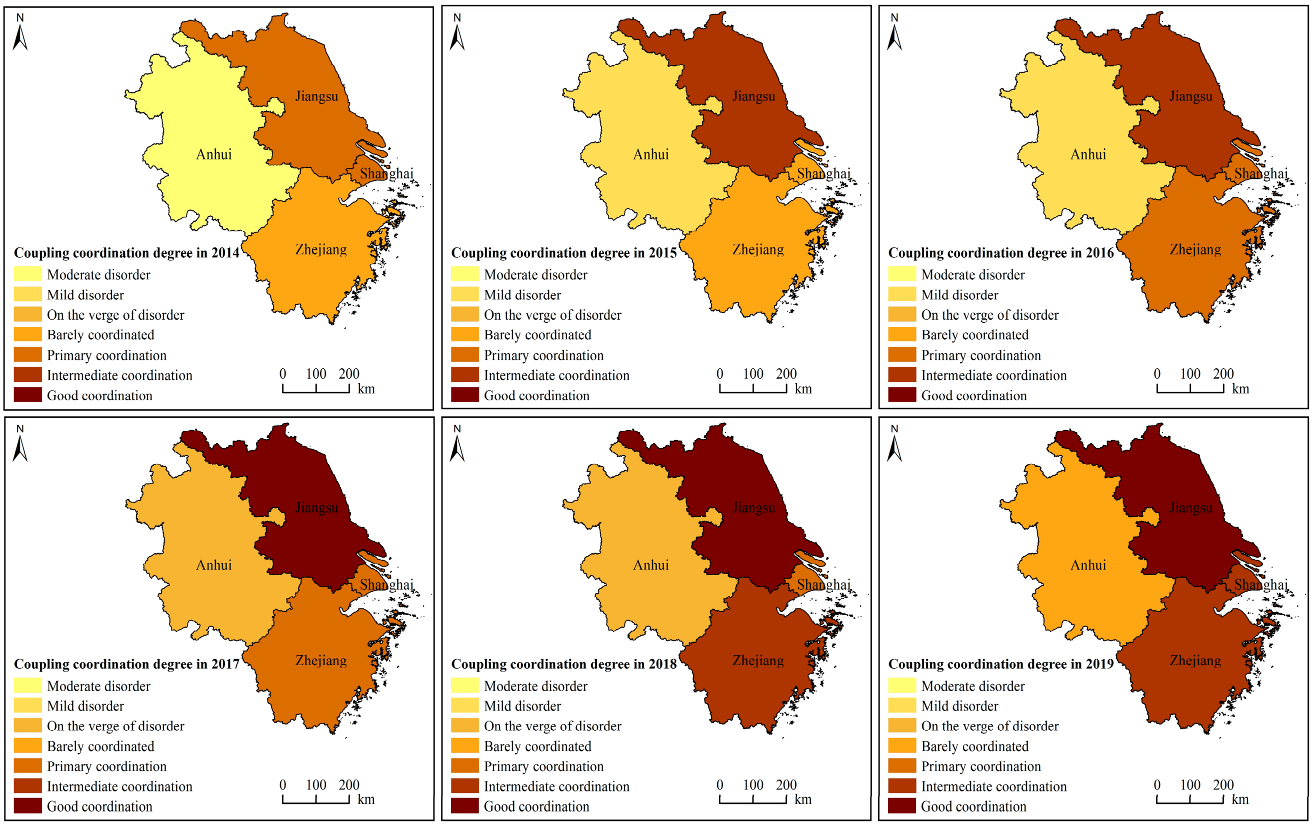


Figure 6. Evolution trends of coupling coordination degree of the innovation EROB composite system in the YRD region.

3.2.3. Coupling and Coordination Obstacle Factors Diagnosis Results

The obstacle degree model was used to calculate the obstacle degree of the subsystem of the regional innovative EROB composite system in the YRD region between 2014–2019. The specific results are shown in Table 6 and its change law is shown in Figure 7.

Table 6. Obstacle degree of the subsystem of the innovation EROB complex system in the YRD.

Year	Region	U1	U2	U3	U4
2014	Anhui	19.59	31.11	26.85	22.45
	Zhenjiang	17.76	29.43	27.13	25.68
	Jiangsu	14.92	24.78	20.83	39.48
	Shanghai	17.92	31.72	32.74	17.62
	Yangtze River Delta	17.55	29.26	26.89	26.31
2015	Anhui	19.88	31.28	26.64	22.20
	Zhenjiang	20.41	29.19	25.33	25.07
	Jiangsu	19.09	24.14	16.23	40.54
	Shanghai	22.98	30.53	30.89	15.59
	Yangtze River Delta	20.59	28.78	24.77	25.85
2016	Anhui	19.72	32.49	26.95	20.84
	Zhenjiang	20.43	30.56	25.33	23.68
	Jiangsu	19.53	23.85	14.93	41.69
	Shanghai	23.59	31.31	31.34	13.76
	Yangtze River Delta	20.82	29.55	24.64	24.99
2017	Anhui	19.70	32.78	27.46	20.06
	Zhenjiang	20.81	30.77	26.10	22.33
	Jiangsu	19.83	23.15	15.28	41.74
	Shanghai	24.53	30.97	32.14	12.35
	Yangtze River Delta	21.22	29.42	25.24	24.12
2018	Anhui	19.83	33.33	26.91	19.93
	Zhenjiang	22.36	30.97	23.40	23.27
	Jiangsu	22.36	22.55	9.42	45.68
	Shanghai	26.41	32.23	30.61	10.76
	Yangtze River Delta	22.74	29.77	22.58	24.91
2019	Anhui	18.56	33.08	28.30	20.06
	Zhenjiang	25.13	27.82	22.24	24.82
	Jiangsu	27.63	14.07	3.31	54.99
	Shanghai	26.87	32.32	30.23	10.59
	Yangtze River Delta	24.55	26.82	21.02	27.61

The obstacle degree model (i.e., Equation (10)), was used to calculate the obstacle degree of each primary index in 2014 and 2019. The calculation results are shown in Table 7, and their changes are shown in Figure 7.

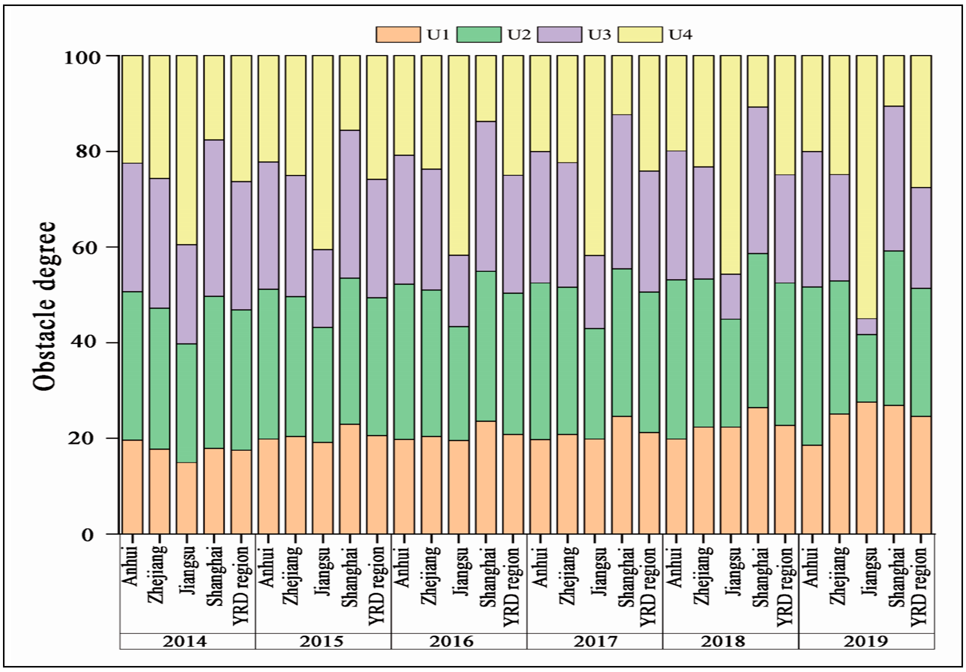
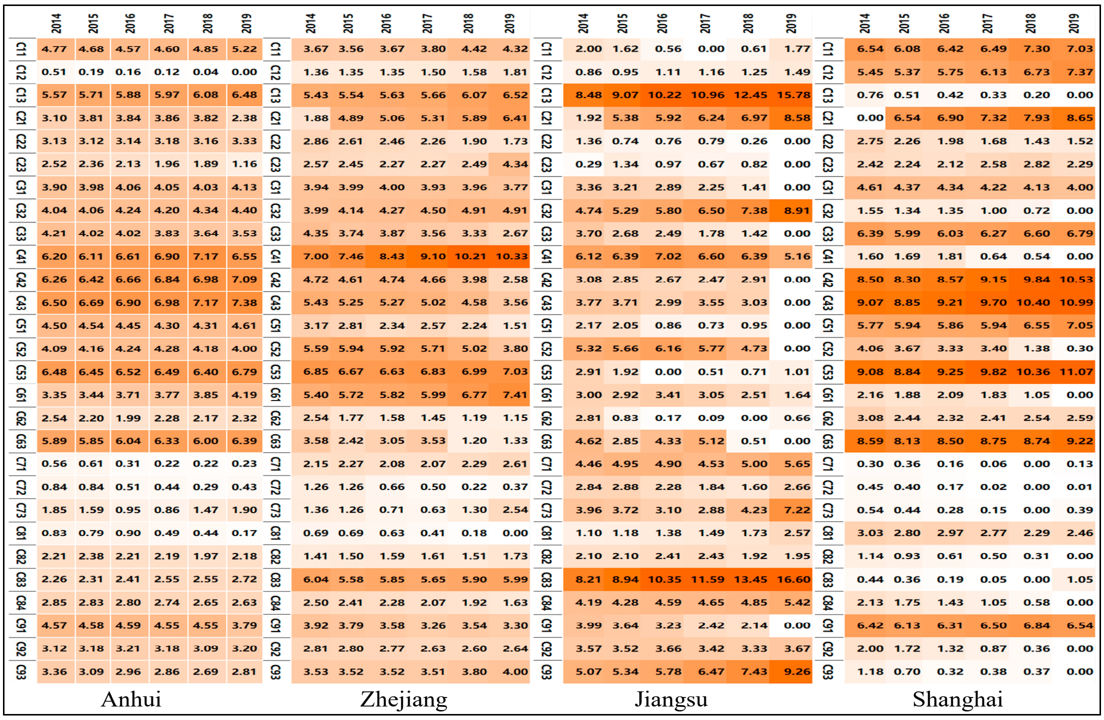


Figure 7. Obstacle degree of the subsystem of the innovation EROB complex system in the YRD.

Table 7. Obstacle scores and ranking of the primary indices in the YRD.

Second-Level Index		**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
2014	Anhui	10.85	8.74	12.15	18.96	15.07	11.78	3.25	8.16	11.05
	Order	5	7	3	1	2	4	9	8	6
	Zhejiang	10.46	7.31	12.28	17.15	15.6	11.52	4.77	10.65	10.27
	Order	6	8	3	1	2	4	9	5	7
	Jiangsu	11.35	3.57	11.81	12.97	10.4	10.43	11.25	15.59	12.63
	Order	5	9	4	2	8	7	6	1	3
	Shanghai	12.75	5.17	12.55	19.16	18.91	13.83	1.29	6.74	9.6
	Order	4	8	5	1	2	3	9	7	6
	Yangtze River Delta	11.35	6.2	12.2	17.06	15	11.89	5.14	10.29	10.89
	Order	5	8	3	1	2	4	9	7	6
2019	Anhui	11.69	6.87	12.06	21.02	15.39	12.91	2.56	7.69	9.8
	Order	5	8	4	1	2	3	9	7	6
	Zhejiang	12.65	12.48	11.35	16.47	12.34	9.9	5.52	9.35	9.94
	Order	2	3	5	1	4	6	9	8	7
	Jiangsu	19.05	8.58	8.91	5.16	1.01	2.3	15.53	26.54	12.92
	Order	2	6	5	7	9	8	3	1	4
	Shanghai	14.4	12.46	10.8	21.52	18.42	11.81	0.53	3.51	6.54
	Order	3	4	6	1	2	5	9	8	7
	Yangtze River Delta	14.45	10.1	10.78	16.04	11.79	9.23	6.04	11.77	9.8
	Order	2	6	5	1	3	8	9	4	7

Finally, the obstacle degree results of the secondary indices calculated by the obstacle degree model were sorted out, and the obstacle factor scores of 28 secondary indices in the six years between 2014–2019 for the three provinces and one city of the YRD region were obtained (Figure 8).



	Anhui						Zhejiang						Jiangsu						Shanghai					
	2014	2015	2016	2017	2018	2019	2014	2015	2016	2017	2018	2019	2014	2015	2016	2017	2018	2019	2014	2015	2016	2017	2018	2019
C11	4.77	4.68	4.57	4.60	4.85	5.22	3.67	3.56	3.67	3.80	4.42	4.32	2.00	1.62	0.56	0.00	0.61	1.77	6.54	6.08	6.42	6.49	7.30	7.03
C12	0.51	0.19	0.16	0.12	0.04	0.00	1.36	1.35	1.35	1.50	1.58	1.81	0.86	0.95	1.11	1.16	1.25	1.49	5.45	5.37	5.75	6.13	6.73	7.37
C13	5.57	5.71	5.88	5.97	6.08	6.48	5.43	5.54	5.63	5.66	6.07	6.52	8.48	9.07	10.22	10.96	12.45	15.78	0.76	0.51	0.42	0.33	0.20	0.00
C21	3.10	3.81	3.84	3.86	3.82	2.38	1.88	4.89	5.06	5.31	5.89	6.41	1.92	5.38	5.92	6.24	6.97	8.58	0.00	6.54	6.90	7.32	7.93	8.65
C22	3.13	3.12	3.14	3.18	3.16	3.33	2.86	2.61	2.46	2.26	1.90	1.73	1.36	0.74	0.76	0.79	0.26	0.00	2.75	2.26	1.98	1.68	1.43	1.52
C23	2.52	2.36	2.13	1.96	1.89	1.16	2.57	2.45	2.27	2.27	2.49	4.34	0.29	1.34	0.97	0.67	0.82	0.00	2.42	2.24	2.12	2.58	2.82	2.29
C31	3.90	3.98	4.06	4.05	4.03	4.13	3.94	3.99	4.00	3.93	3.96	3.77	3.36	3.21	2.89	2.25	1.41	0.00	4.61	4.37	4.34	4.22	4.13	4.00
C32	4.04	4.06	4.24	4.20	4.34	4.40	3.99	4.14	4.27	4.50	4.91	4.91	4.74	5.29	5.80	6.50	7.38	8.91	1.55	1.34	1.35	1.00	0.72	0.00
C33	4.21	4.02	4.02	3.83	3.64	3.53	4.35	3.74	3.87	3.56	3.33	2.67	3.70	2.68	2.49	1.78	1.42	0.00	6.39	5.99	6.03	6.27	6.60	6.79
C41	6.20	6.11	6.61	6.90	7.17	6.55	7.00	7.46	8.43	9.10	10.21	10.33	6.12	6.39	7.02	6.60	6.39	5.16	1.60	1.69	1.81	0.64	0.54	0.00
C42	6.26	6.42	6.66	6.84	6.98	7.09	4.72	4.61	4.74	4.66	3.98	2.58	3.08	2.85	2.67	2.47	2.91	0.00	8.50	8.30	8.57	9.15	9.84	10.53
C43	6.50	6.69	6.90	6.98	7.17	7.38	5.43	5.25	5.27	5.02	4.58	3.56	3.77	3.71	2.99	3.55	3.03	0.00	9.07	8.85	9.21	9.70	10.40	10.99
C51	4.50	4.54	4.45	4.30	4.31	4.61	3.17	2.81	2.34	2.57	2.24	1.51	2.17	2.05	0.86	0.73	0.95	0.00	5.77	5.94	5.86	5.94	6.55	7.05
C52	4.09	4.16	4.24	4.28	4.18	4.00	5.59	5.94	5.92	5.71	5.02	3.80	5.32	5.66	6.16	5.77	4.73	0.00	4.06	3.67	3.33	3.40	1.38	0.30
C53	6.48	6.45	6.52	6.49	6.40	6.79	6.85	6.67	6.63	6.83	6.99	7.03	2.91	1.92	0.00	0.51	0.71	1.01	9.08	8.84	9.25	9.82	10.36	11.07
C61	3.35	3.44	3.71	3.77	3.85	4.19	5.40	5.72	5.82	5.99	6.77	7.41	3.00	2.92	3.41	3.05	2.51	1.64	2.16	1.88	2.09	1.83	1.05	0.00
C62	2.54	2.20	1.99	2.28	2.17	2.32	2.54	1.77	1.58	1.45	1.19	1.15	2.81	0.83	0.17	0.09	0.00	0.66	3.08	2.44	2.32	2.41	2.54	2.59
C63	5.89	5.85	6.04	6.33	6.00	6.39	3.58	2.42	3.05	3.53	1.20	1.33	4.62	2.85	4.33	5.12	0.51	0.00	8.59	8.13	8.50	8.75	8.74	9.22
C71	0.56	0.61	0.31	0.22	0.22	0.23	2.15	2.27	2.08	2.07	2.29	2.61	4.46	4.95	4.90	4.53	5.00	5.65	0.30	0.36	0.16	0.06	0.00	0.13
C72	0.84	0.84	0.51	0.44	0.29	0.43	1.26	1.26	0.66	0.50	0.22	0.37	2.84	2.88	2.28	1.84	1.60	2.66	0.45	0.40	0.17	0.02	0.00	0.01
C73	1.85	1.59	0.95	0.86	1.47	1.90	1.36	1.26	0.71	0.63	1.30	2.54	3.96	3.72	3.10	2.88	4.23	7.22	0.54	0.44	0.28	0.15	0.00	0.39
C81	0.83	0.79	0.90	0.49	0.44	0.17	0.69	0.69	0.63	0.41	0.18	0.00	1.10	1.18	1.38	1.49	1.73	2.57	3.03	2.80	2.97	2.77	2.29	2.46
C82	2.21	2.38	2.21	2.19	1.97	2.18	1.41	1.50	1.59	1.61	1.51	1.73	2.10	2.10	2.41	2.43	1.92	1.95	1.14	0.93	0.61	0.50	0.31	0.00
C83	2.26	2.31	2.41	2.55	2.55	2.72	6.04	5.58	5.85	5.65	5.90	5.99	8.21	8.94	10.35	11.59	13.45	16.60	0.44	0.36	0.19	0.05	0.00	1.05
C84	2.85	2.83	2.80	2.74	2.65	2.63	2.50	2.41	2.28	2.07	1.92	1.63	4.19	4.28	4.59	4.65	4.85	5.42	2.13	1.75	1.43	1.05	0.58	0.00
C91	4.57	4.58	4.59	4.55	4.55	3.79	3.92	3.79	3.58	3.26	3.54	3.30	3.99	3.64	3.23	2.42	2.14	0.00	6.42	6.13	6.31	6.50	6.84	6.54
C92	3.12	3.18	3.21	3.18	3.09	3.20	2.81	2.80	2.77	2.63	2.60	2.64	3.57	3.52	3.66	3.42	3.33	3.67	2.00	1.72	1.32	0.87	0.36	0.00
C93	3.36	3.09	2.96	2.86	2.69	2.81	3.53	3.52	3.52	3.51	3.80	4.00	5.07	5.34	5.78	6.47	7.43	9.26	1.18	0.70	0.32	0.38	0.37	0.00

Figure 8. Obstacle scores of the secondary indices in the YRD region.

Based on the scores of 28 secondary index obstacle factors, we combed the change law of 28 secondary index obstacle degrees of the three provinces and one city in each year between 2014–2019. On this basis, we showed the change trends of 28 obstacle factors that affected the coupling coordination development of the regional innovation EROB complex system over six years to identify the main obstacle factors shown in Figure 9.

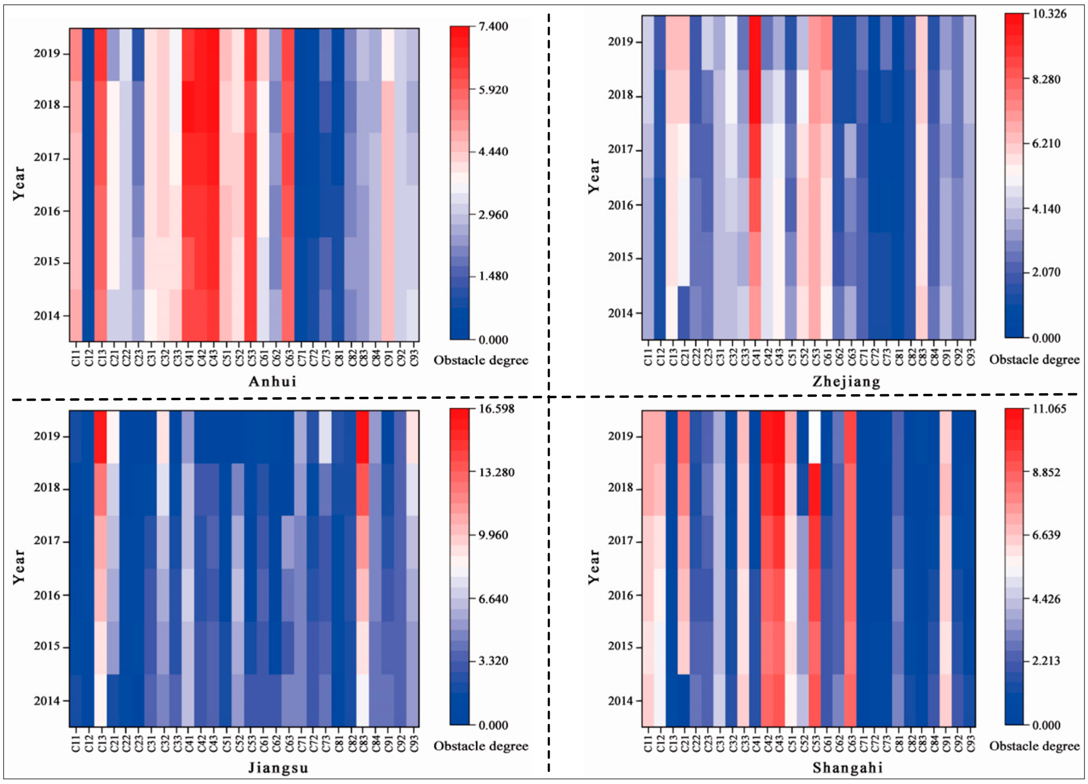


Figure 9. Changing trends in obstacle factors in the YRD region from 2014 to 2019.

3.3. Result Analysis

3.3.1. Analysis of the Comprehensive Development Coefficient of the Regional Innovation EROB Composite System in the YRD

From the perspective of the region as a whole, the regional comprehensive development coefficient of the YRD shows a steady upward trend, which is the result of the joint action of the four subsystems; however, each subsystem provides a different contribution. Specifically, between 2014–2019, the innovation benefit subsystem was the driving force for the comprehensive development coefficient. It can be seen that the main force behind the innovation-driven development in the YRD has been transformed, and the "multiplier effect" of innovation has been brought into play. However, from the actual level of the comprehensive development coefficient, despite the growth trend of this index over the six-year period, the average value was only 0.42955, with an average annual growth rate of 10.45%. By 2019, the comprehensive development coefficient was only 0.5469, with much room for improvement remaining.

Within the region, the comprehensive development coefficient always maintained Jiangsu > Shanghai > Zhejiang > Anhui from 2014 to 2017. From 2018 to 2019, the comprehensive development coefficient ranked Jiangsu > Zhejiang > Shanghai > Anhui. Jiangsu was found to rank first among the three provinces and one city of the YSD region, mainly owing to the outstanding performance of innovation output and resources, which indicates that Jiangsu focuses on the investment of innovation resources and supports its enterprises. However, while Jiangsu has obvious shortcomings in innovation benefits, Shanghai has obvious advantages, indicating that Shanghai has made remarkable achievements in the industrialization of innovation output. Zhejiang's development index scores were not prominent, and the development indices of the four subsystems tended to be coordinated.

The comprehensive development coefficient of Anhui's innovative EROB composite system maintained continuous growth over the six-year period; however, there was a large gap compared with the other two provinces and the city. These results are consistent with reality. Although Anhui has joined the YRD region, Anhui's development stage, level, and foundation show large gaps in comparison to those of Shanghai, Jiangsu, and Zhejiang. In addition, innovation benefits and innovation environments were shown to be important driving forces that support the comprehensive development of Anhui's innovation system. It can be seen that Anhui has made great efforts to play a "combined fist" of policies, stimulate potential scientific and technological innovation, and gradually achieve results that promote the transfer and transformation of various innovative outputs.

3.3.2. Analysis of the Coupling Coordination Degree of the Regional Innovation EROB Composite System in the YRD

From the perspective of the region as a whole, the coupling degree of the innovation EROB composite system in the YRD was high (i.e., nearly above 0.9000), indicating that the innovation EROB composite system in the YRD has strong coupling and is in a high-level coupling stage. However, the high-level coupling stage does not represent a high-level development stage, which can be confirmed by the comprehensive development coefficient of the innovation system. For example, the coupling degree in 2019 was 0.9596; however, the comprehensive development coefficient was less than 0.6, indicating a low level of comprehensive development. At the same time, the high-level coupling does not represent high-level coordinated development. The empirical results show that the coordination degree of the regional innovation EROB composite system maintained growth; however, the coordination degree obviously lagged behind the coupling degree. For example, in 2019, the coupling degree of the regional innovation EROB composite system was 0.9596. while the coordination degree was 0.7155. Thus, the two did not achieve coordinated development.

From the perspective of the regional interior, the evolution processes of the coupling degree and coordination degree of the regional innovation EROB composite system in the three provinces and one city were not the same. From 2014 to 2019, Anhui's coupling degree increased from the confrontation stage to the high-level coupling stage. Anhui's coordination degree changed from moderate disorder in 2014 to barely coordinated in 2019. It can be seen that the coupling development of the Anhui regional innovation EROB composite system outpaced the coordination development. The coupling degrees of the innovation EROB composite systems in Jiangsu, Shanghai, and Zhejiang were at the high-level coupling stage between 2014–2019. Regarding coordination degree, Zhejiang moved from barely coordinated in 2014 to displaying intermediate coordination in 2019. Jiangsu shifted from primary coordination in 2014 to good coordination in 2019; In 2014, Shanghai's primary coordination decreased to barely coordinated in 2015, and the coordination degree continued to grow in subsequent years, realizing intermediate coordination in 2019. Among the three provinces and one city, the innovation EROB composite systems in Jiangsu, Shanghai, and Zhejiang entered a coordination development state, while that of Anhui remained in a barely coordinated state.

3.3.3. Obstacle Factor Analysis of Coupling and Coordination of the Regional Innovation EROB Composite System in the YRD Region

From the perspective of the region as a whole, between 2014–2018, innovation resources (U2) ranked first among the subsystems restricting the coupling and coordinated development of the regional innovation EROB composite system in the YRD region. By 2019, innovation benefits (U4) replaced innovation resources (U2) as the primary obstacle system. When the integration strategy of the YRD was implemented, the obstacles of system and mechanism were broken, so that the scientific and technological innovation resources can be integrated and utilized across regions. However, the radiation and spillover effects of scientific and technological innovation in the YRD need to be strengthened, and the transfer and transformation of scientific and technological achievements to the economy and society should be actively promoted. In 2019, the order of obstacle degree of each primary index in the YRD region was as follows: C4 > C1 > C5 > C5 > C8 > C3 > C2 > C9 > C7. Among the secondary indicators, sales revenue of new products in high-tech industries (C53), number of students in colleges and universities per 100,000 population (C41), R&D personnel input (C43), R&D personnel full-time equivalent (C42), and public library collection per unit population (C13) were the main obstacle factors affecting the coupling coordination development of the innovation EROB composite system in the YRD.

From the perspective of regional interior, the obstacle degree of the subsystem of Anhui's regional innovation EROB composite system between 2014–2019 was "U2 > U3 > U4 > U1," and the order of obstacle degree of each primary index in 2019 was "C4 > C5 > C6 > C3 > C1 > C9 > C8 > C2 > C7 >". Among them, innovation resources (U2) represented the main obstacle to the coupling coordination development of Anhui's innovation system. Among the secondary indicators, R&D personnel input (C43), R&D personnel full-time equivalent (C42), sales revenue of new products in high-tech industries (C53), number of students in colleges and universities per 100,000 population (C41), and public library collection per unit population (C13) were the main obstacle factors affecting the coupling and coordinated development of Anhui's innovation system. These findings indicate that the cultivation and introduction of high-level talent will become the focus of Anhui's innovative development in the future.

From 2014 to 2018, the obstacle degree of each subsystem of Zhejiang's regional innovation EROB composite system was "U2 > U3 > U4 > U1," while in 2019, it became "U2 > U1 > U4 > U3." Although there were fluctuations, innovation resources (U2) remained the main obstacle to the coupling coordination development of Zhejiang's innovation system. In 2019, the order of obstacle degree for each primary index was as follows: C4 > C1 > C2 > C5 > C3 > C6 > C9 > C8 > C7. Among the secondary indicators, the number of students in colleges and universities per 100,000 population (C41), number of published scientific papers (C61), sales revenue of new products in high-tech industries (C53), public library collection per unit population (C13) and total investment in fixed assets (C21) were the main obstacle factors affecting the coupling and coordinated development of Zhejiang's innovation system. Furthermore, Zhejiang did not have abundant human resources reserves. Although, akin to Shanghai and Jiangsu, Zhejiang was in the lead for realizing development in regional economic integration, there was a large gap in C41 compared with Shanghai and Jiangsu. In addition, there were too few high-tech enterprises, the core competitiveness was not sufficiently strong, and regional development was not sufficiently balanced; thus, the cultivation of high-tech industrialization needs to be strengthened.

The subsystem obstacle degree of Jiangsu's regional innovation EROB composite system was "U4 > U2 > U3 > U1" in 2014, "U4 > U2 > U1 > U3" between 2015–2018, and "U4 > U1 > U2 > U3" in 2019. Innovation benefits (U4) were shown to have always been the main obstacle to the coupling and coordinated development of Jiangsu's innovation system. In 2019, the order of the obstacle degree of each primary index of Jiangsu's innovation system was as follows: C8 > C1 > C7 > C9 > C3 > C2 > C4 > C6 > C5. Among the secondary indicators, traffic accident fatalities (C83), public library collection per unit population (C13), proportion of added value of tertiary industry in GDP (C93), R&D expenditure intensity (C32); and total investment in fixed assets (C21) were the main obstacle factors affecting the coupling and coordinated development of Jiangsu's innovation system. Between 2015–2019, traffic accident fatalities (C83) in Jiangsu ranked first among the three provinces and one city and increased continuously during the study period. Although Jiangsu was in the lead for realizing development in regional economic integration, there was a large gap in public library collection per unit population (C13), compared with Shanghai and Zhejiang. Therefore, attention needs to be paid here.

Between 2014–2017, the subsystem obstacle degree of Shanghai's regional innovative EROB composite system was "U3 > U2 > U1 > U4," while between 2018–2019, it was "U2 > U3 > U1 > U4." The substitution of innovation resources (U2) for innovation output (U3) was shown to become the main obstacle to the coupling coordination development of Shanghai's regional innovation EROB composite system. In 2019, the order of obstacle degree for each primary index was as follows: C4 > C5 > C1 > C2 > C6 > C3 > C9 > C8 > C7. Among the secondary indicators, sales revenue of new products in high-tech industries (C53), R&D personnel input (C43), R&D personnel full-time equivalent (C42), patent application authorization (C63), and total investment in fixed assets (C21) were the main obstacle factors affecting the coupling and coordinated development of Shanghai's innovation system. The results indicate that Shanghai has laid a preliminary foundation for high-tech industry development, with its leading development in regional economic integration. However, the actual status and economic contribution of high-tech industries have remained unsatisfactory, and the innovation abilities of high-tech industries and R&D personnel investment need to be enhanced.

3.4. Discussion and Management Enlightenment

3.4.1. Discussion

Compared with extant literature [41,42,66], this research has some advantages. First, a four-dimensional evaluation system of coupling coordination development of regional innovation EROB composite systems was constructed. The RIS was divided into innovation environment, innovation resource, innovation output, and innovation benefit subsystems, which enriches the RIS literature. Second, by using a data-driven integrated model method, this study quantitatively measured, evaluated, and identified the coupling coordination development level of regional innovation EROB composite systems to put forward optimization suggestions. This enriches the literature on regional coordinated development. Promoting the coupling coordination development of regional innovation EROB composite systems is an internal requirement of regional sustainable development and has an important practical significance for constructing innovative countries.

Based on the analysis results, we put forward the following targeted optimization suggestions.

(1) From the Overall Regional Level

Promoting the construction of coupling coordination development of the YRD regional innovation EROB composite system and continuously enhancing the ability of regional collaborative innovation are key policies for improving the competitiveness of the regional economy. First, it is necessary to improve the innovation layout, integrate innovation resources such as science and technology and talent, improve innovation resource allocation efficiency, and build a coordinated innovation community in the YRD region. Second, it is also necessary to fully embrace the role of the government, tilt toward independent innovation enterprises in resource allocation and public services and provide a suitable environment for scientific and technological innovation as well as achievement transformation. Focus should be placed on high-tech industries as the main driving force of regional economic structure adjustment, industrial technology upgrading, and economic growth. Third, there is a need to establish and improve the transformation system of scientific and technological achievements in high-tech industries, promote the industrialization of high-tech, and speed up the transformation of scientific and technological achievements into real productive forces. Finally, we will support innovation subjects such as colleges and universities, scientific research institutions, and industrial parks in the region to vigorously cultivate R&D talents and lay a solid foundation for the "landing" of regional innovation.

(2) From the Internal Regional Level

Anhui should increase the training and introduction of high-level talent. First, Anhui should increase investment in education and increase enrollment at ordinary colleges and universities. Second, Anhui should establish and improve R&D personnel introduction subsidy plans, actively provide special subsidies, support scientific research projects as well as innovation and entrepreneurship projects, and improve R&D personnel's initiative and enthusiasm. At the same time, Anhui should support enterprises, universities, scientific research institutes, and other innovative groups. It should also support social forces to increase investment in basic research, stimulate the innovation vitality, and motivation of society as a whole, and create an influential source of scientific and technological innovation.

Zhejiang should increase investment in higher education resources, pay attention to training talent among undergraduate and graduate students, and cultivate high-level talent for the development of scientific and technological innovation. At the same time, while Zhejiang should continue to expand the scale of high-tech industries, optimize the industrial structure, and enhance the agglomeration effect of high-tech industries, it should also promote the transformation of scientific and technological achievements into real productive forces, pay attention to the cultivation of high-tech industrialization, and improve sales revenue for new products.

In terms of traffic safety supervision, Jiangsu should make scientific policies and empower it with science and technology. Focus should be directed toward the special rectification of traffic safety, with traffic safety management system and management ability modernization being constantly promoted. In addition, it is necessary to continue to deepen the public cultural service system in Jiangsu, strengthen the allocation of public cultural service resources and infrastructure construction, and expand the continuous investment of funds into cultural fields. In particular, Jiangsu should strengthen the supply capacity of public book resources, increase the public library collection per capita, fully meet the needs of the people in this regard, and create a good innovative cultural atmosphere.

Shanghai should actively guide high-tech enterprises to take the development path of independent and sustainable innovation. At the policy level, it is necessary to establish and improve the internal positive economic incentive mechanism of high-tech industries; these should not be limited to general capital support and preferential tax policies. Regarding the scientific research system, Shanghai should promote the connection between the use, disposal, and income of scientific and technological achievements and the personal social status and economic return of R&D personnel, as well as stimulate and mobilize the innovation and creativity enthusiasm of R&D personnel, so as to facilitate more technological achievements with transformation value and form an industry. At the same time, it is necessary to establish and improve the intellectual property protection system throughout society, encourage intellectual and technological invention, and create a social atmosphere in which knowledge and talent are respected.

3.4.2. Management Enlightenment

Combined with the above research, we get the following three management enlightenment:

First, the coupling coordination development level of innovation environment, innovation resources, innovation output, and innovation benefits is related to regional innovation ability and sustainable development. An objective evaluation of the coupling coordination development level of the four subsystems within a specific RIS can help the government clarify the obstacles toward innovation and development and provide direction for taking the measures required to improve regional innovation ability.

Second, good policy support is necessary to understand the relationships between innovation environments, innovation resources, innovation output, and innovation benefits. This includes understanding the strategic focus of science, technology, and talent development, and striving to solve major science, technology, and talent bottlenecks that restrict economic transformation and improvement. It is also necessary to accelerate the organic integration of scientific and technological progress and talent cultivation with industrial development and comprehensively improve regional innovation ability.

Third, in the new global scientific and technological revolution and industrial transformation, promoting China's regional industrial-technological transformation, optimization, and improvements with scientific and technological innovation are greatly significant for consolidating the high-quality development of regional economies. It is necessary to work hard to deepen scientific and technological system and mechanism reform, build an efficient regional scientific and technological innovation system, and improve the output conversion rate of scientific and technological innovation, so as to better rely on scientific and technological innovation to promote the transformation and development of regional economies.

4. Conclusions

Building an RIS is an urgent requirement for realizing high-quality and sustainable development of regional economies. To realize sustainable regional development, the subsystems of innovation environments, innovation resources, innovation output, and innovation benefits need to achieve coupling and coordinated development, to promote in RISs the formation of a state of benign interaction, harmonious symbiosis, and collaborative progress. Therefore, there is an urgent need to measure, evaluate, identify, and optimize the coupling and coordinated development of regional innovation EROB composite systems, to promote the sustainable and high-quality development of regional economies.

This study proposed a data-driven measurement, evaluation, and identification method for the coupled and coordinated development of regional innovation EROB composite systems. The innovations are as follows. First, the evaluation index system of coupling coordination development of regional innovation EROB composite systems was constructed. The index system includes four dimensions—innovation environment, innovation resources, innovation output, and innovation benefits—which make the measurement and evaluation of regional innovation ability more comprehensive. Second, this study constructed a data-driven integrated model method for measuring, evaluating, and identifying the coupling coordination development of regional innovation EROB composite systems. Using this method, we can objectively measure the comprehensive development coefficient, quantitatively evaluate coupling coordination development levels, and scientifically diagnose the main obstacle factors affecting coupling and coordinated development. Third, build a "measurable, evaluable, identifiable, and optimized" comprehensive mechanism for the coupling coordination development of regional EROB composite systems. According to the measurement, evaluation, and identification results of the coupling coordination development of regional innovation EROB composite systems, accurate measures are taken, and the optimization path to promote its coupling coordination development is put forward.

This study has potential theoretical and practical significance. Regarding the theoretical significance, first, based on the coupling mechanism of RIS, this study constructs an evaluation system of a regional innovation EROB composite system based on the four dimensions of innovation environment, resources, output, and benefits, which can provide a new direction for RIS research. Second, on the basis of the data-driven theory, a quantitative integrated model method based on the entropy weight method, coupling coordination degree model (CCDM), and obstacle degree model is constructed to more accurately and objectively describe the coupling coordination model and spatial structure of a regional innovation EROB composite system, which enriches the RIS evaluation model. Third, based on coupling and coordination theory, this study identifies and explains the internal relationship and action mechanism of the subsystems in the RIS "black box," and improves the theoretical framework of research on the internal coupling coordination development of RIS. Regarding practical significance, first, this study aimed to build a data-driven comprehensive evaluation mechanism of a "measurable, evaluable, identifiable, and optimized" regional innovation EROB composite system. Second, the study aimed to provide a decision-making basis for accelerating the high-quality development of regional innovative EROB composite systems and building a high-quality development demonstration area. Third, this study aimed to help the innovation subjects (governments, universities, research institutions, and companies) in an RIS to gain a comprehensive and objective understanding of the development level and obstacles of a regional innovation EROB composite system and seek effective solutions and improvement countermeasures.

However, the research on regional innovation composite systems is a complex system engineering. In view of the complexity of indicators and the availability of data, the integrity of the evaluation system still needs to be further discussed. In addition, in future research, it can be combined with ecological theory to construct a framework for research on regional innovation ecosystems, explore the collaborative relationships between the internal elements of innovation ecosystems, and strive to provide support for evaluating regional innovation ecosystems.

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