Comprehensive Evaluation of China's Regional Industry-University-Research Institutions Collaborative Innovation System Based on Entropy Method and Coupling Coordination Model

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Abstract. This study uses panel data from 30 provinces and cities in China from 2015 to 2019 to divide the regional collaborative innovation system into three major subsystems: enterprises, universities, and scientific research institutions .According to the entropy method, the 27 indicators selected in this paper are given different objective weights, and a measurement model of the coupling coordination degree of industry-university-research institutions is constructed, and finally the results of the coupling coordination degree of the regional collaborative innovation system are obtained.

Key Words. Regional Collaborative Innovation System, Coupling And Coordination Degree, Entropy Weight Method

1 Introduction

On June 23, 2021, Premier Li Keqiang presided over the State Council executive meeting and pointed out that in recent years, various localities and departments have implemented innovation-driven development strategies and vigorously promoted innovation. It promotes the upgrade of old kinetic energy, the rapid growth of new kinetic energy, and accelerates the conversion of new and old kinetic energy. Cook and others put forward their own point of view, that is, enterprises, universities, scientific research institutions and innovation entities in other fields jointly build a regional industry-university-research collaborative innovation system. It has a regional organizational structure system that supports and produces innovation drivers and Innovation subject.[1] Each innovation subject in the regional innovation system uses the sharing, expansion and diffusion of knowledge, capital, technology, information and other elements as the basis for innovation, giving full play to the individual's own integration and agglomeration advantages to form a kind of convergence of collaborative innovation form. Most of the knowledge and technological innovation generated by the collaborative innovation system come from innovation entities such as enterprises, universities, and scientific research institutions. Therefore, the degree of coupling and coordination between innovation entities reflects the operating conditions of the collaborative innovation system to a certain extent, and at the same time affects the integration of advantageous resources of the innovation entities, the flow of knowledge resources, and the development of the collaborative innovation system. Usually, each innovation subsystem in the collaborative innovation system achieves the purpose of

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improving the synergy effect of the innovation system by sharing advantageous resources.[2] And this coupling system has the characteristics of openness, complexity and nonlinearity.[3] In measuring the degree of coupling and coordination of regional collaborative innovation systems, existing researchers have used the DEA method to measure the efficiency of the symbiosis network of China's regional collaborative innovation systems;[4] using the triple helix mutual information algorithm to evaluate the regional coupling effect of the differentiation of government, industry, university and research institute;[5] using the characteristics of the public side of the new collaborative center to analyze the synergy effect and coupling degree of the innovation system;[6] and some related researchers have constructed a regional collaborative innovation system coupling and coordination degree model To calculate the degree of coupling and coordination of regional collaborative innovation systems.[7]

In short, the current related research on collaborative coupling coordination mainly focuses on the measurement of coupling coordination mechanism, influencing factors, degree and so on. A small number of research scholars regard the level of coordinated development of regional collaborative innovation systems as the research focus. This research continues this research direction, selects three innovation subsystems of enterprises, universities, and scientific research institutions as models to measure the degree of coupling, and evaluate the current situation of coupling and coordinated development of regional collaborative innovation systems in 30 provinces and cities in China.

2 COUPLING AND COORDINATION BETWEEN THE MAIN BODIES OF THE REGIONAL COLLABORATIVE INNOVATION SYSTEM

Li Chenglong defines the coupling coordination of collaborative innovation systems as: the interdependence and interaction between the innovation subsystems of enterprises, universities, and scientific research institutions. The interconnection density between collaborative innovation systems represents the innovation capabilities of the collaborative innovation system.[8] The sub-systems of regional collaborative innovation coordinated, interacted and developed under the effect of non-linearity, moving from disorder to order. Enterprises use their capital, talents, information and other resources to continuously pursue technological innovation, thereby increasing productivity, developing new products, and ultimately obtaining economic benefits through product output. The dominant position of an enterprise is reflected in its key role in technology application and achievement transformation. However, compared with universities and scientific research institutions, enterprises lack innovation in basic theoretical knowledge. Therefore, enterprises need to collaborate and innovate with universities and scientific research institutions. As the output terminal of applied talents and innovative talents, colleges and universities are committed to theoretical and basic knowledge research, thus forming their own advantages in knowledge gathering. However, compared with enterprises, colleges and universities still have shortcomings in the application and transformation of knowledge resources. Coupling and coordination between systems can effectively promote the application of technology and the transformation of results in colleges and universities. The main tasks of scientific research institutions are the research and development of knowledge and technology, use their own resources and scientific research advantages, and jointly establish collaborative innovation alliances with enterprises and universities to improve the process of transforming science and technology into productivity. Therefore, due to system differences among enterprises, universities, and scientific research institutions, their development goals are different. In the process of coupling and coordination of the innovation system, each subject needs to coordinate and integrate its own structure and behavior with other subjects in the system to innovate the subject's superior resources, thereby improving resource utilization efficiency, reducing risk hazards, and realizing the greatest value of innovation change. Integrating the superior resources of the collaborative innovation subsystem, realizing the coupling and coordination among the themes of collaborative innovation alliances such as enterprises, universities, scientific research institutions, etc., will help to enhance regional innovation and economic capabilities.

3 RESEARCH AND DESIGN

3.1 Variable selection

The synergy among the innovation subjects within the regional collaborative innovation system makes the originally disorderly system transform into an orderly direction. What is the degree of this synergy? Has it reached a state of benign interaction? We can use the degree of coupling coordination to measure the level of coupling and coordination of regional collaborative innovation systems. Based on existing research, this paper selects three major innovation entities: enterprises, universities, and scientific research institutions as the three subsystems of the regional collaborative innovation system; and the innovation subsystem is evaluated from the three dimensions of innovation input, innovation activities, and innovation output.[7] According to the research of existing scholars, this research selects 27 measurable indicators that can represent the three major innovation subsystems to measure the coupling and coordination of regional collaborative innovation systems. The basic principle of determining weights based on the entropy method gives different indicators selected in this article. At the same time, the coupling and coordination degree model is used to further measure the objective weight of, and finally the measurement result of the coupling coordination degree of the regional collaborative innovation system are obtained,[9] and the index weights are shown in Table 1.

3.2 Model construction

3.2.1 System index weight measurement model

Aiming at the determination of the index weights of the various subsystems in the regional collaborative innovation system, this paper uses the entropy weight method to assign values. Entropy method can judge the degree of dispersion between indicators, and it is a comprehensive evaluation method that can evaluate multiple objects and multiple indicators at the same time. Therefore, in order to effectively prevent the subjective factors in determining the weight from affecting the research, this paper uses the entropy weight method to measure the weight of each index of each subsystem. The specific measurement steps are as follows:

3.2.1.1Data standardization

In order to eliminate the impact on the research results due to the different dimensions of data units, attributes, etc., we standardized the collected data[10]:

Positive indicators:

$$Y_{ij}= \frac{X_{ij}-min(X_i)}{max(X_i)-min(X_i)} \tag{1}$$

Negative indicators:

$$Y_{ij}= \frac{max(X_i)-X_{ij}}{max(X_i)-min(X_i)} \tag{2}$$

Table 1. Strategic Emerging Industry Collaborative Innovation Countermeasure Mechanism

system	index	Weights
enterprise	Internal expenditure of R&D funds (ten thousand yuan)	0.0856
	Government funds in R&D expenditures (ten thousand yuan)	0.0619
	New product development funds (ten thousand yuan)	0.0990
	New product sales revenue (ten thousand yuan)	0.0938
	Number of R&D projects (items)	0.1009
	R&D project staff (person-years)	0.0974
	R&D project funding (ten thousand yuan)	0.0879
	Number of enterprise R&D institutions (a)	0.1559
	Full-time equivalent of R&D personnel (person-years)	0.0947
	Number of valid invention patents (pieces)	0.1229
Research institutions	Internal expenditure of R&D funds (ten thousand yuan)	0.1362
	Government funds in R&D expenditures (ten thousand yuan)	0.1430
	Number of R&D projects (items)	0.1101
	R&D project staff (person-years)	0.0953
	R&D project funding (ten thousand yuan)	0.1499
	Number of scientific research institutions (a)	0.0346
	Number of scientific papers published (pieces)	0.1133
	Number of valid invention patents (a)	0.1253
	Full-time equivalent of R&D personnel (person-years)	0.0925
Colleges	Internal expenditure of R&D funds (ten thousand yuan)	0.1537
	Government funds in R&D expenditures (ten thousand yuan)	0.1559
	Number of R&D projects (items)	0.0908
	R&D project staff (person-years)	0.0891
	R&D project funding (ten thousand yuan)	0.1587
	Number of scientific papers published (papers)	0.0906
	Number of valid invention patents (a)	0.1721
	Full-time equivalent of R&D personnel (person-years)	0.0891

3.2.1.2 Measure the weight of each indicator

Calculate the characteristic proportion of index j in year i, P_{ij}:

$$P_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{m} Y_{ij}} \qquad (0 \le P_{ij} \le 1) \tag{3}$$

Calculate the information entropy according to the entropy calculation formula, e_j:

$$e_j = -\frac{1}{\ln n}\sum_{i=1}^{n} P_{ij}\, ln\,(P_{ij}) \quad (0 \leq e_j \leq 1) \tag{4}$$

Calculate the information entropy redundancy, D_j:

$$D_j = 1 - e_j \tag{5}$$

Calculate the weight of index j, w_j:

$$w_j = \frac{D_j}{\sum_{i=1}^{n} D_j} \tag{6}$$

Calculate the comprehensive evaluation score, U_i:

$$U_j = \sum_{i=1}^{n} Y_{ij} w_j \tag{7}$$

Among them, U represents the comprehensive evaluation score, n represents the number of indicators, and w_j represents the weight of the j-th indicator. Therefore, the higher the comprehensive score of the index, the better, and finally the U value of each index can be compared.

3.2.2 Coupling Coordination Measure Model

The term coupling degree first comes from the field of physics, in view of the relatively similar coupling relationship between different systems. This research uses the coupling coordination model to measure the coupling and coordination development of the three innovation subsystems. The specific models are as follows:

$$C = 2\left[\frac{U_1 U_2 U_3}{(U_1+U_2)(U_1+U_3)(U_2+U_3)}\right]^{\frac{1}{3}} \tag{8}$$

In the formula, C represents the degree of coupling in physics, and U_1, U_2, and U_3 respectively represent the comprehensive development index of enterprise innovation subsystem, scientific research institution innovation subsystem, and university innovation subsystem.

In order to evaluate the regional collaborative innovation system more objectively, this research further builds a coupling coordination degree model, the specific model is as follows:

$$D = \sqrt{C \times T} \tag{9}$$

$$T = \alpha U_1 + \beta U_2 + \gamma U_3 \tag{10}$$

In the formula, D represents the degree of coupling and coordination, C represents the degree of coupling in physics, T represents the comprehensive development index of the innovation subsystem of enterprises, scientific research institutions, and universities, α, β, and γ represent undetermined coefficients, and $\alpha+\beta+\gamma = 1$. Since the enterprise is the link in the entire collaborative activities, it plays a key guiding role in the transformation of science and technology, while scientific research institutions and universities are responsible for the task of generating and transferring new knowledge. Therefore, the three sub-systems are involved in the entire collaboration. The actors in the innovation system play an approximately equivalent role. This article is sets $\alpha=0.4$, $\beta=0.3$, $\gamma=0.3$.[7]

4 Empirical results and analysis

This article is based on the analysis of panel data from more than 30 provinces and cities in China from 2015 to 2019, and it is excluded due to the lack of data in the Tibet Autonomous Region, Hong Kong and Macao administrative regions. The data comes from the "China Statistical Yearbook" and "China Science and Technology Statistical Yearbook". The relevant variables of the enterprises in the data use the data of enterprises above designated size in the Statistical Yearbook. In order to eliminate the data differences caused by different dimensions between the data, all the data are standardized before using the entropy method.

4.1 Analysis of Measurement Results of Coupling and Coordination Degree of Regional Collaborative Innovation System

In this paper, the entropy method is used to calculate the weights of 27 indicators of the coupling coordination degree of regional collaborative innovation systems, and the coupling coordination degree model is used to measure the coupling coordination degree of the collaborative innovation systems of 30 provinces and cities in China. The calculation results are shown in Table 2.

The calculation results show that from 2015 to 2019, the level of coupled and coordinated development of regional collaborative innovation systems in 30 provinces and cities in China has been improved as a whole. The results show that under the new economic normal, the degree of coupling and coordination of regional collaborative innovation systems is continuously improving, and it also reflects the gradual improvement of the coupling relationship and the degree of coordination between the innovation subsystems. The frequency and efficiency of knowledge interaction and joint innovation among various innovation entities have increased. However, most provinces and cities in China have a low degree of coupling and coordination, and their development speed is slow. Only a few provinces such as Jiangsu, Guangdong, Beijing and Shanghai are at a relatively high level of development. There are also differences in the spatial distribution of the degree of coupling and coordination of regional collaborative innovation systems in 30 provinces and cities in China. The calculation results in Table 2 show that the top six provinces and cities with the coordinated and coordinated development level of the regional collaborative innovation system are all located in the eastern coastal areas of China. Jiangsu Province, Guangdong Province and Beijing rank among the top three in terms of the degree of coupling and coordination of China's regional collaborative innovation system. Among them, from 2015 to 2019, the average value of the coupling coordination degree of the regional collaborative innovation system in Jiangsu Province was 0.645, and Guangdong Province ranked second with an average value of 0.615, followed by Beijing with an average value of 0.599.[11]

Under the new economic normal, Jiangsu and Guangdong provinces have realized the complementary advantages of the innovation entities in the system by virtue of the development and growth of their private enterprises, the agglomeration advantages of collaborative innovation resources, the efficient flow of innovation elements, and the effective transformation of scientific and technological achievements. Beijing has abundant scientific and educational resources, a strong economic foundation and level of economic development. Beijing has many independent innovation demonstration parks under the auspices of many countries, which provide a knowledge and technological innovation platform for promoting better collaboration and development among innovative entities such as enterprises, scientific research institutions, and universities. From 2015 to 2019, the three provinces and cities at the bottom of the level of coupled and coordinated development of China's regional collaborative innovation system are Ningxia, Hainan and Qinghai. The degree of coupling and coordination of regional collaborative innovation systems in these three provinces is extremely low, with an average of only 0.074, 0.073, and 0.040 over the years. The calculation results can also reflect from the side that the economic structure imbalance in Ningxia, Hainan, and Qinghai is more prominent. The province's high-tech industries are beginning to take shape and are small in scale, and the number of strategic emerging industry companies is relatively small. Enterprises have low independent innovation capabilities, and scientific research institutions lack sufficient financial support, resulting in low efficiency of technological innovation. At the same time, the number of colleges and universities affiliated to the three provinces is small and the brain drain is serious. It is difficult to meet the local talent and knowledge needs for collaborative innovation, which restricts the cultivation of innovative talents and the development of innovative technologies. In addition, there are few regional collaborative innovation platforms and the lack of channels for each innovation subject to quickly obtain complementary resources, which hinders the effective transformation and application of knowledge among various innovation subsystems. Therefore, the degree of coupling and coordination of the regional collaborative innovation system is relatively low, which indicates that each innovation subject has not formed an effective collaborative coupling effect in the system.

Table 2. Coupling and coordination degree of collaborative innovation systems in various provinces and regions from 2015 to 2019

years / area	2015	2016	2017	2018	2019	average value	Sort
Beijing	0.568	0.570	0.592	0.612	0.654	0.599	3
Tianjin	0.319	0.317	0.312	0.306	0.299	0.311	14
Hebei	0.260	0.274	0.292	0.293	0.311	0.286	16
Shanxi	0.186	0.189	0.201	0.213	0.223	0.202	23
Inner Mongolia	0.148	0.156	0.156	0.158	0.163	0.156	26
Liaoning	0.317	0.325	0.338	0.341	0.360	0.336	11
Gui ling	0.230	0.228	0.231	0.222	0.262	0.234	20
Hi long jiang	0.255	0.253	0.245	0.238	0.251	0.248	18
Shang hai	0.464	0.478	0.499	0.518	0.554	0.503	4
Jiang Su	0.591	0.619	0.643	0.668	0.706	0.645	1
Zhe jiang	0.427	0.445	0.465	0.492	0.527	0.471	5
An Hui	0.327	0.334	0.353	0.364	0.383	0.352	10
Fu Jian	0.267	0.288	0.308	0.325	0.347	0.307	15
Jiang xi	0.204	0.216	0.236	0.258	0.290	0.241	19
Shan dong	0.435	0.447	0.477	0.482	0.480	0.464	6
Henan	0.303	0.311	0.325	0.337	0.362	0.327	13
Hu bei	0.361	0.372	0.392	0.417	0.446	0.398	8
Hu nan	0.296	0.305	0.327	0.344	0.368	0.328	12
Guang dong	0.520	0.570	0.619	0.662	0.706	0.615	2
Guang xi	0.195	0.201	0.215	0.219	0.231	0.212	22
Hainan	0.066	0.071	0.071	0.076	0.080	0.073	29
Chongqing	0.227	0.248	0.265	0.292	0.308	0.268	17
Si chuan	0.370	0.387	0.412	0.435	0.458	0.413	7

Guizhou	0.150	0.157	0.173	0.179	0.194	0.171	24
Yunnan	0.197	0.202	0.211	0.220	0.240	0.214	21
Shaanxi	0.345	0.352	0.365	0.384	0.409	0.371	9
Gan Su	0.163	0.165	0.166	0.171	0.186	0.170	25
Qinghai	0.021	0.039	0.046	0.045	0.050	0.040	30
Ningxia	0.052	0.067	0.076	0.084	0.092	0.074	28
Xinjiang	0.133	0.139	0.136	0.139	0.136	0.137	27

5 Conclusion

This paper evaluates the development status of the regional collaborative innovation system coupling and coordination by constructing a model of the coupling coordination degree of the regional collaborative innovation system. The results show that the degree of coupling and coordination of my country's regional collaborative innovation system has not risen significantly from 2015 to 2019, and there are large differences in level. The level of coupled and coordinated development of regional collaborative innovation systems in the eastern coastal areas of China is relatively high, while the level of development in the western and inland areas is relatively low, showing a characteristic of high in the east and low in the west.

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