

Research on the Coupling Coordination Development of Industry-University-Research, Regional Economy and Ecological Environment and Their Spatial Spillover Effects

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Abstract: This paper applies the coupling model to study the coupling coordination development of industry-university-research, ecological environment and regional economy in 30 provinces and cities in China from 2009 to 2019, on the basis of which, this paper further applies the spatial Durbin model to measure the spatial spillover effects of the three subsystems. The results show that: (1) During the study period, China's IUR-Economy-Ecology system is characterized by high coupling degree and low coupling coordination degree, in which 83% of China's regions are lagging in industry-university-research, and the regional distribution shows a diamond-shaped distribution of "high in the east, flat in the northeast and the middle, and low in the West ". (2) The IUR-Economy-Ecology, economic and ecological system has obvious spatial polarization effect. (3) The industry-university-research system has spatial diffusion effect, which indicates that promoting industry-university-research cooperation is conducive to the promotion of the balanced regional development. (4) The industry-university-research innovation system, relative to the economic and ecological systems, has a "wooden barrel effect" in the process of promoting the coupled and coordinated development of IUR-Economy- Ecology system, and promoting the development of industry-university-research innovation system can most efficiently improve the "capacity ceiling" of the total system.

Keywords: Industry-University-Research, Regional Economy Ecological Environment, Coupled Coordination Degree Model, Spatial Spillover.

1. Introduction

In recent years, China has paid more and more attention to the sustainability and stability of economic development, from seeking high-speed economic development to high-quality economic development. On March 11, 2021, the fourth session of the 13th National People's Congress voted to pass the resolution on the 14th Five-Year Plan for national economic and social development, looking at the outline of the 14th Five-Year Plan, the three "new" has become a consistent logical main line, compared with the previous five-year plan, it has more prominently reflected the requirements of basing on the new development stage, implementing the new development concept, building a new development pattern, and promoting high-quality development. General Secretary Xi Jinping pointed out that "High-quality development is development that can well meet the people's ever-growing needs for a better life, development that reflects the new concept of development, development that makes innovation the first driving force, coordination becomes the endogenous characteristic, green becomes the universal form, openness becomes the path we must take, and sharing the fundamental purpose." In addition to ensuring the stability and balance of economic growth, high-quality development also needs to coordinate the sustainable and internal driving forces of development. Since 1978, China 's regional economic growth has been largely at the expense of high consumption of resources and energy. Nowadays, the deteriorating ecological environment is restricting the sustainability of regional economic development; on the other hand, in recent years, China 's economic development is

facing increasing downward pressure, and China has entered a new normal in economic development, but the driving force of innovation-driven needed for economic development is insufficient. Coordinating the development relationship among regional economy, ecological environment and scientific and technological innovation has important practical significance for China 's high-quality development at this stage. For the issue of scientific and technological innovation, the " 14th Five-Year Plan " proposes to " improve the market-oriented mechanism of technological innovation, strengthen the dominant position of enterprises in innovation, promote the agglomeration of various innovative elements to enterprises, and form a technological innovation system with enterprises as the main body, market-oriented, industry-university-research-application deep integration. " Therefore, this paper constructs a regional science and technology innovation system from the perspective of industry-university-research cooperation, measures the coordinated development of the system with the ecological environment and regional economy, summarizes the experience and lessons, and discusses how to coordinate the internal relationship among the three in the new era and new stage.

2. Literature References

For the relationship between scientific and technological innovation, ecological environment and regional economy, domestic and foreign scholars have carried out rich research from multiple perspectives. From the perspective of research objects, previous studies have focused on the relationship between science and technology and economy [1,2], ecology and economy [3,4]. There are few studies on their internal

relations by combining the three, mainly after 2018 [5,6]. The literature on the relationship between the three from the perspective of industry-university-research is even rarer. From the perspective of research methods, the literature on quantitative analysis of the relationship between the three can be divided into multi-index evaluation system and few-index evaluation system. The literature with more indexes in the evaluation system mainly adopts the coupling coordination degree model, factor analysis method [7], grey correlation method [8], etc., among which the method of confirming weight is mainly divided into subjective weighting method and objective weighting method (entropy weighting method, TOPSIS [9], etc.). The evaluation system generally uses these variables directly to construct a regression model according to the research purpose [10]. Both economic development and scientific and technological innovation have strong spatial spillover effects. However, there are few studies on this using spatial econometric models. From the perspective of research scale, the existing literature covers a very complete range of scales such as national, [11] provincial, [6] economic circle, [9] and prefecture-level cities.

As far as the coordinated development of industry-university-research and regional economy and ecological environment is concerned, Chinese scholars began to explore the theory as early as the beginning of the 20th century. Henry Etzkowitz and Loet Leydesdorff (1995) introduced the triple helix model in biology to analyze the interaction between government-industry-university-research [13]. Subsequently, in 2006, Chinese scholar Zhou Chunyan and Henry Etzkowitz proposed the university-public-government sustainable development triple helix as a supplement to the university-enterprise-government triple helix model [14], in order to explore the theoretical model of industry-university-research and sustainable development. This article is one of the earliest literature on the combination of industry-university-research and sustainable development in China, but the results have not been widely used in other literature. Zeng Lijun et al. (2016) studied the sustainable development of science and technology industry and resource-based cities. Based on China's data, the positive effect of industry-university-research on regional sustainable development was demonstrated through empirical analysis. The conclusion of the literature shows that cities with limited resources for industry-university-research and innovation can also promote the sustainable coordinated development of science and technology industry and resource-based cities through comprehensive support for industry-university-research collaborative innovation [15].

In summary, in terms of literature, previous studies have mainly focused on the pairwise analysis of innovation, ecology and economy, while there are few studies on the ternary relationship among the three, and less attention has been paid to the spatial spillover effects of the three in the process of coordinated development. Scientific and technological innovation, ecological environment and economic development are not independent and isolated from each other. As an important strategy of China's regional innovation mechanism, the development of industry-university-research innovation system and its correlation with ecology and economy cannot be ignored. Therefore, it is necessary and valuable to include the industry-university-research innovation system as an indicator to measure regional scientific and technological innovation to study its coupling and coordinated development with regional

economy and ecological environment and spatial spillover effects.

3. Variable Selection and Processing

3.1. Variable selection

Based on the existing research result and following the systematic, scientific, complete and comparable evaluation indicators, this paper constructs a ternary system coordinated development evaluation system from three aspects: industry-university-research, regional economy and ecological environment.

In 2008, China launched a R&D resource inventory, and the statistical caliber of R&D indicators changed before and after this time. In 2013, the National Bureau of Statistics carried out a survey on the income and expenditure and living conditions of urban-rural integrated households. Before and after 2013, the survey scope, survey methods and indicators of urban and rural household surveys were different. This paper eliminated the two indicators of residents' disposable income and residents' consumption ability. In addition, due to the large number of indicators involved in this paper, considering the availability of data, the data of Tibet, Hong Kong, Macao and Taiwan are not discussed in this paper. Therefore, this paper selects the panel data of 30 provinces and cities from 2009 to 2019 for analysis.

3.2. Data processing and index system

Road network density = (highway mileage + railway mileage + inland waterway mileage) / area.

Material capital stock: Based on the total investment in fixed assets of the whole society, the perpetual inventory method is adopted, and the depreciation rate is set to 5%. The calculation of the capital stock in the base period follows the method of Fan Gang (2011), [23] that is, the total investment in fixed assets of the base period is multiplied by 10% as the initial material capital stock.

Human capital stock: This paper uses the product of the number of employees at the end of the year and the number of years of education of the labor force to measure the human capital stock of each province and city. This calculation method highlights the important role of labor quality in the production process to a certain extent. The calculation method adopts the method of Peng Guohua (2005) [24].

The external expenditure of R&D refers to the actual expenses paid by the outside units to carry out R & D activities, which can better measure the level of R&D cooperation investment among universities, scientific research institutes and enterprises. Because the data of R&D external expenditure of scientific research institutes are missing in many provinces, this paper does not select this index; the turnover of technical contracts has two statistical calibers of output region and flow region. This paper selects the turnover of technical contracts in the output region of the technology market to measure the level of collaborative innovation output in the region. The total import and export volume of goods is divided into two statistical calibers according to the location of the consignee and the consignor, and according to the location of the source of goods and the domestic destination. This paper selects the import and export of goods divided by the location of the source of goods and the domestic destination to measure the level of regional foreign trade. The data related to the conversion of US dollars to RMB in this paper are converted according to the average

exchange rate of US dollars to RMB in the current year.

Table 1. Evaluation system of coordinated development of industry-university-research-regional economy-ecological environment ternary system

Subsystem	Module	Factor
I-U-R innovation system	Enterprise	R&D input : R&D, internal expenditure, R&D personnel FTE
		R&D output : number of patent applications and new products, yield of new products
	University / Research institute	R&D input : R&D, internal expenditure, R&D personnel FTE
		R&D output : number of patent applications, sci-tech papers, sci-tech works
	Government	R&D services : government R&D expenditure, number of patent grants
		Degree of attention : proportion of government funds for R&D funds, proportion of sci-tech expenditure in government finance
	Innovation environment	Infrastructure : road network density, internet penetration rate, mobile phone penetration rate
		Innovation demand : R&D investment intensity, proportion of the tertiary industry, proportion of the population with college degree or above
	Collaborative innovation	Synergy input : external expenditure of enterprise R&D funds, external expenditure of university R&D funds
		Collaborative platform : number of university sci-tech parks
Collaborative results : technical contract turnover		
Regional economic system	Economic scale	Regional GDP, total retail sales of consumer goods, total import and export of goods, gross fixed asset formation
	Industrial structure	The value added of the primary industry, the proportion of the secondary industry, and the value added of the tertiary industry
	Development benefits	Urban unemployment rate*, human capital stock
Environment system	Ecological endowments	Water resources per capita, air quality in major cities (days of air quality reaching or exceeding level 2 in a year)
	Environmental pollution	Total chemical oxygen demand emission *, total ammonia nitrogen emission *, total sulfur dioxide emission *, industrial solid waste generation *
	Governance capacity	Industrial wastewater treatment facilities management ability, industrial wastewater treatment facilities management ability, industrial solid waste comprehensive utilization rate
	Investment for treatment	Wastewater treatment investment, waste gas treatment investment, industrial pollution control investment

Note : with '*' is a negative indicator

The data of this paper are from the ' *China Statistical Yearbook* ', ' *China Statistical Yearbook for Science and Technology* ', ' *China Torch Statistical Yearbook* ', ' *China Environmental Statistical Yearbook* ', ' *China Regional Innovation Capability Evaluation Report* ' and the ' *National Economic and Social Development Statistical Bulletin* ' of the National Bureau of Statistics and provinces and cities from 2009 to 2019.

4. Research Method

4.1. Coupling coordination degree model based on entropy weighting method

At present, the weighting methods can be divided into two categories : subjective weighting method and objective weighting method. In this paper, the entropy weighting method in the objective weighting method is used to determine the weight of each index, which avoids the deviation caused by human factors to a certain extent. Entropy is a physical concept in thermodynamics, which is used to represent the degree of chaos or disorder of the system. It is widely used in the field of social economy. The basic principle of the entropy weighting method is to determine the objective weight according to the variability of the index. Generally speaking, if the information entropy of an index is smaller, the degree of deviation of the index is greater, the amount of information provided is more, and the weight is greater. Like entropy, coupling also comes from the concept of physics, which is used to describe the phenomenon of mutual influence and interaction between two or more systems. The coupling coordination degree model involves the sum calculation of three indexes, which are the coupling degree C

value, the coordination degree T value and the coupling coordination degree D value. When searching and reading the paper, the author found that there were some errors in the calculation formula of coupling degree and coupling coordination degree in some literatures. Liu Chunlin summarized the common errors in the calculation of coupling degree [25]. This paper draws on the correct calculation method summarized in this literature.

4.2. Spatial econometric model Spatial correlation

(1) Spatial correlation

Ignoring the spatial correlation between variables in the study of regional economic growth is often the wrong setting [26]. Before using the spatial econometric model, it is necessary to test the spatial correlation of the coupling degree of the three-element system of the explained variable. Spatial autocorrelation refers to the potential interdependence between the observed data of variables in the same distribution interval. In this paper, the spatial distribution of the coupling coordination degree of the ternary system is measured by Moran's I index.

(2) Build measurement model

After using the global Moran's I index calculation to determine the spatial agglomeration of the coupling coordination degree of the ternary system, it is necessary to establish a spatial econometric model. The commonly used spatial econometric models are spatial lag model (SLM), spatial error model (SEM) and spatial Durbin model (SDM). SDM is the general form of the other two models. According to the following test results, we can determine the time fixed effect model of SDM used in this paper:

$$Y = \rho WY + \sum_{i=1}^3 \beta_i X_i + \sum_{i=1}^3 \theta W X_i + \mu + \varepsilon \quad (1)$$

In the above formula, Y represents the coupling coordination degree of the ternary system, X_1, X_2, X_3 represent the coupling coordination degree of the triple helix, economy and ecosystem respectively, μ represents the time fixed effect, W is the spatial matrix, WY and $W X_i$ represent the spatial lag terms of the dependent variable and the independent variable respectively, ρ and θ are used to measure the influence of the dependent variable and the independent variable on Y in the adjacent area, β_i is the regression coefficient, and ε is the error term.

5. Empirical Analysis

5.1. Spatio-temporal analysis of coordinated development of IUR-economy-ecosystem

Based on the entropy weighting method, this paper obtains the annual evaluation values of each system in 30 provinces and cities, and uses the calculation results of the coupling

degree and coupling coordination degree formula to measure the interaction and coordinated development level of IEE systems in each region and each year. The calculation results of the coupling coordination degree of each system in 30 provinces and cities and four major regions from 2009 to 2019 are shown in Table 2. Due to the length of the article, this paper lists the average calculation results of each province and city from 2009 to 2019 and analyzes them. The division of coordination types in this paper is improved on the basis of Zhou Cheng 's method , and the lag type is judged by the coupling coordination degree of each system rather than the evaluation value. Firstly, the order of coupling coordination degree of each subsystem is the same as the evaluation value, which does not affect the judgment of lag type. Secondly, it can intuitively judge the difference of the coordinated development level of each subsystem. Finally, because the calculation results of the provincial and regional coupling models are generally high coupling degree and low coupling coordination degree, it is more necessary to analyze the reasons through the coupling coordination degree of each subsystem. Therefore, this paper uses the coupling coordination degree of each subsystem to judge the coordination type.

Table 2. System coupling model calculation results for each province and four regions from 2009 to 2019

Region	C value of IEE system	D value of IUR system	D value of economic system	D value of ecosystem	D value of IEE system	Coordination type
Eastern region	0.8896	0.3890	0.5707	0.3804	0.4349	Ecological lag
Central region	0.8997	0.2746	0.5255	0.4215	0.3655	IUR lag
Northeast region	0.9650	0.2846	0.5187	0.3812	0.3420	IUR lag
Western region	0.8731	0.2137	0.4331	0.3947	0.3005	IUR lag
Beijing	0.7510	0.6175	0.4637	0.2205	0.4256	Ecological lag
Tianjin	0.9844	0.3101	0.4671	0.2875	0.3163	Ecological lag
Hebei	0.8393	0.2570	0.5935	0.4260	0.4021	IUR lag
Shanxi	0.8447	0.2102	0.4413	0.4299	0.3186	IUR lag type
Inner Mongolia	0.7899	0.1666	0.4893	0.4619	0.2964	IUR lag
Liaoning	0.9587	0.3315	0.5779	0.4106	0.3946	IUR lag
Jining	0.9686	0.2551	0.4703	0.3414	0.3025	IUR lag
Heilongjiang	0.9678	0.2672	0.5077	0.3917	0.3288	IUR lag
Shanghai	0.9076	0.5219	0.5755	0.3192	0.4338	Ecological lag
Jiangsu	0.9392	0.5120	0.7246	0.4782	0.5810	Ecological lag
Zhejiang	0.9483	0.4075	0.6298	0.4829	0.4835	IUR lag
Anhui	0.9431	0.2994	0.5238	0.4319	0.3801	IUR lag
Fujian	0.8948	0.2641	0.5753	0.4619	0.3714	IUR lag
Jiangxi	0.8888	0.2250	0.4845	0.4320	0.3229	IUR lag
Shandong	0.8982	0.3844	0.6840	0.4599	0.5333	IUR lag
Henan	0.8522	0.2770	0.5760	0.3962	0.4020	IUR lag
Hubei	0.9528	0.3549	0.5650	0.4253	0.4040	IUR lag
Hunan	0.9166	0.2811	0.5625	0.4136	0.3655	IUR lag
Guangdong	0.8303	0.4768	0.6859	0.4531	0.5534	Ecological lag
Guangxi	0.8448	0.2007	0.4983	0.4493	0.3280	IUR lag
Hainan	0.9031	0.1388	0.3080	0.2149	0.2491	IUR lag
Chongqing	0.9562	0.2516	0.4753	0.3378	0.3075	IUR lag
Sichuan	0.9517	0.3629	0.5941	0.4300	0.4111	IUR lag
Guizhou	0.8791	0.1785	0.4135	0.3900	0.2758	IUR lag
Yunan	0.8836	0.2174	0.4721	0.4523	0.3194	IUR lag
Shaaxi	0.9856	0.3523	0.4877	0.3943	0.3678	IUR lag
Gansu	0.9597	0.2190	0.3671	0.3233	0.2740	IUR lag
Qinghai	0.6457	0.1035	0.2562	0.3875	0.2403	IUR lag
Ningxia	0.8528	0.1225	0.2856	0.2944	0.2025	IUR lag
Xinjiang	0.8553	0.1762	0.4246	0.4208	0.2830	IUR lag

Through the analysis of Table 2, it is not difficult to draw the following conclusions. This paper will analyze the problems found and their causes as follows:

First, distribution of high coupling degree and low coupling coordination degree. The coupling degree in most areas is above 0.8, which belongs to good coordination, while the coupling coordination degree is basically below 0.5, which is in a state of imbalance. Tianjin, Jilin, Gansu and Ningxia are the most prominent, and the difference between coupling coordination degree and coupling degree reaches more than 0.65, among which Tianjin is the ecological lagging type, and the other three provinces are the backward type of production, university and research. After comprehensively dividing the coordinated development types of various regions, the right medicine can be applied in the planning of regional development, and more reasonable development regulation can be carried out. The high coupling degree means that the interaction between the three systems of production, university and research, economy and ecology is very strong, and the coupling degree does not distinguish between advantages and disadvantages, while the low coupling degree means that the development of the three departments of production, university and research, economy and ecology is unbalanced. Combining the results of coupling degree and coupling coordination degree, it can be concluded that the development conditions of the three are generally mutually restricted at a low level. The results show that regional economy, scientific and technological innovation and ecological environment have a strong interactive relationship in the process of China's economic transformation from high-speed development to innovation-driven high-quality development. However, the loss of ecological resources and the backwardness of innovation and development brought by the period of high-speed economic development are becoming "stumbling blocks" to high-quality development. In the process of economic development, we need to pay enough attention to the development of scientific and technological innovation and ecological environment, and grasp the synergistic development side of the close connection between the three, and overcome their mutual constraints.

Second, there is no economic lag in the coordination type, and most of them are backward in production, study and research. On the one hand, spanning the three five-year plans from 2009 to 2019, China's economic development has made all-round and pioneering historical achievements, and the coordination type of the coupling model calculation results without economic lag fully reflects the achievements made in China's economic development. On the other hand, the regional development of China's industry-university-research cooperation is unbalanced. The overall situation of poor cooperation between industry, university and research cannot be ignored, which is also reflected in this paper. In the coordination type, the proportion of regions lagging behind industry, university and research reaches 83%. As an important system in China's regional innovation strategy, although it was proposed early and has been highly valued by local governments, the relevant legislation of industry-university-research lags behind and is only limited to regulating the rights and obligations of a certain link or subject of industry-university-research, which does not provide a good policy environment for the development of

industry-university-research, which is not conducive to the synergy and interaction of various innovation subjects. Only looking at the coupling coordination degree of industry-university-research system, it can be found that the coupling coordination degree of Hainan, Guizhou, Ningxia, Qinghai and Xinjiang is below 0.2, which belongs to the serious imbalance type and restricts each other on the basis of low level development. The industry-university-research coupling coordination degree of Beijing, Shanghai and Jiangsu is above 0.5, and the coupling coordination degree of Guangdong Province and Zhejiang Province reached above 0.5 in 2017 and 2019, respectively, which belongs to mutual promotion on the basis of high-level development. In the context of industry-university-research collaborative innovation, it is necessary to combine the stability of high-quality development and growth, fully grasp the knowledge spillover effect among various innovation subjects and regions, and avoid excessive concentration of various elements in a certain region, which will lead to a vicious circle brought by polarization effect under fierce competition in regions with weak basic conditions and knowledge absorption capacity.

Third, by observing the extreme value of the calculated results and the difference value, it can be found that, on the whole, among the mean values of the three subsystems of 30 provinces and cities, the coupling coordination degree gap between industry, university and research institute and regional economy is the largest, which is 0.2248; The gap between the coupling coordination degree of regional economy and ecosystem is the smallest, which is 0.1213, indicating that the development status of industry-university-research, ecology and economy in China from 2009 to 2019 was economy > ecology > industry-university-research. Due to the long time span of the data in this paper, comparing the above results with the data in 2019, In the average difference of the three subsystems in 30 provinces and cities, the coupling coordination degree between industry, university and regional economy is still the largest, which is 0.221; However, the smallest gap of coupling coordination degree is between production, university and research and ecological environment, which is 0.1464. Combined with the coupling coordination degree of each subsystem, the overall trend of rising, this result can show that China's high-quality development strategy has narrowed the gap between the coupling coordination degree of ecological environment, production, university and research and regional economy. Locally, the order of the coupling coordination degree of IEE system is eastern region > central region > Northeast region > Western region. In the regional economic development, only the coupling coordination degree of western region is lower than 0.5, and it is not in the state of coordinated development. The coupling coordination degree of other four regions of the system is not more than 0.5. In terms of individual subsystem development, the most unbalanced one is Beijing's industry-university-research and ecological environment, and the difference of coupling coordination degree is the largest, which is 0.397. The smallest gap is in the regional economy and ecological environment of Ningxia and Xinjiang, which are 0.009 and 0.004 respectively, but the balance between these two regions is the best on the basis of low development level.

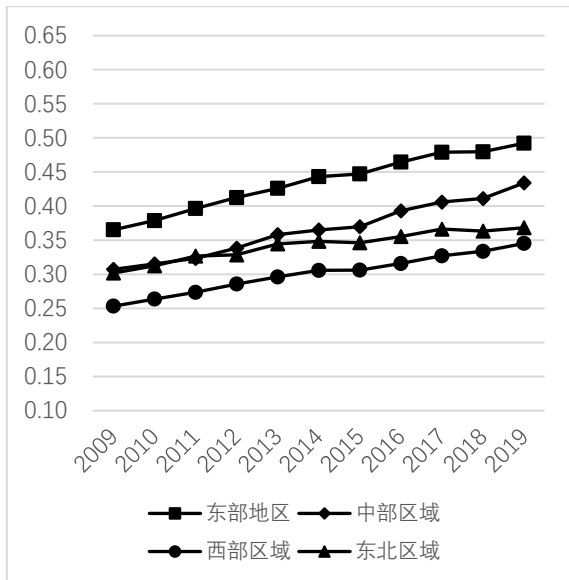


Figure 1. Coupling coordination degree of IEE system in subregions

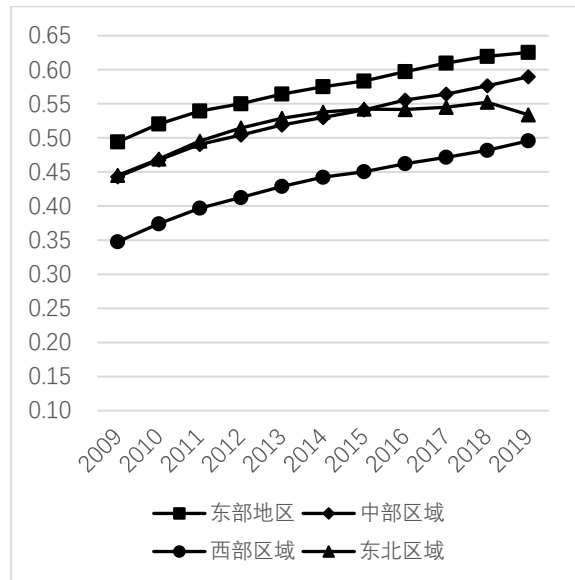


Figure 2. Coupling coordination degree of economic system in subregions

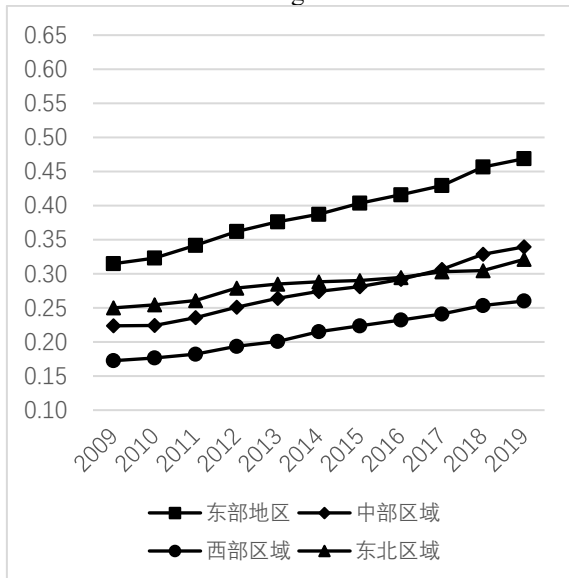


Figure 3. Coupling coordination degree of IUR system in subregions

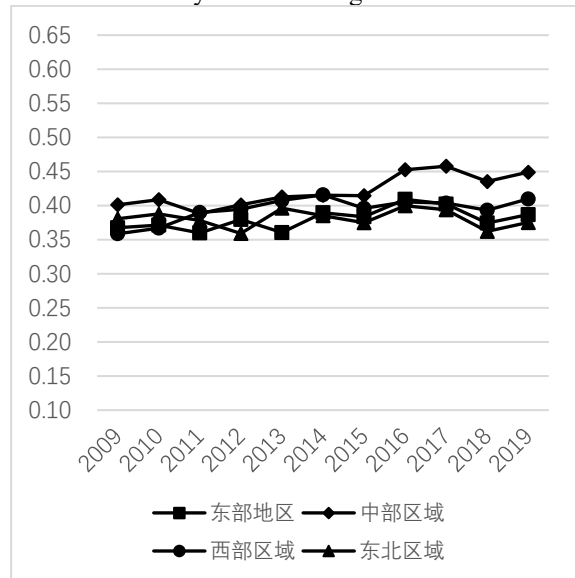


Figure 4. Coupling coordination degree of ecosystem in subregions

From Figure 1 to Figure 4 as a whole, China's ternary system, industry-university-research system and economic system show an obvious upward trend with a large change range. Compared with the data in 2009 and 2019, the degree of increase has increased by a coordination level, that is, the degree of increase of more than 0.1 is the coupling coordination degree of regional economic system in eastern, central and western China. And the coupling coordination degree of production, university and research and ternary system in eastern and central China. It is worth noting that the coupling coordination degree of ecological environment system in China's four major regions fluctuated from 2009 to 2019, among which the coupling coordination degree of ecological environment system in Northeast China in 2019 decreased by 0.006 compared with 2009, which indicates that the coupling and coordination development of ecological environment in China needs to be in terms of ecological efficiency. It is necessary to take full account of the differences between different regions in terms of economic and technological development level, economic scale and environmental conditions, give local governments reasonable space for exploration, realize structural adjustment and

mechanism optimization, and further improve the ecological compensation mechanism to prevent negative policy results such as economic inefficiency caused by ecosystem protection. At an early date, we will guide the coupled and coordinated development of the ecological environment from fluctuations to an upward trend.

Secondly, from the partial point of view of Figure 1 to Figure 4, in addition to the ecological environment system, the regional differences in the coupled and coordinated development of other systems in China are distributed in a rhomboid shape, with the most obvious difference between east and west, and the smallest gap in the central and northeast regions, which is in line with the basic national conditions of China's current regional differences and unbalanced development, and China will also be in a state of unbalanced and inadequate development for a long time. To give full play to the leading role of the eastern region in this issue, the modernization of the developed region and the governance of the problem region are not antagonistic relations, the two are mutually promoting to a certain extent. For the situation of regional differences in coordinated development, the following paper also discusses how to promote the balanced

and coordinated development of regional ternary systems through the analysis of the spatial spillover effects of each system.

5.2. Moran's I global autocorrelation test

In the context of Stata16.0, this paper tests whether the coupling coordination degree of IEE systems in 30 provinces and cities from 2009 to 2019 has spatial correlation, and the test results are shown in Table 3. On the whole, the global Moran 'I index is positive and passes the significance level test of 5%, indicating that the coupled coordination degree of IEE system has a significant global correlation, that is, the value of the coupled coordination degree of IEE system in each province is the spatial distribution pattern of the agglomeration of neighboring provinces. The results in Table 3 confirm that the coupling coordination degree of IEE systems in each province presents a significant spatial cluster phenomenon in space, so it is necessary to include the spatial econometric model in the study of the impact of the coupling coordination degree of each system on the coupling coordination degree of IEE systems.

Table 3. Global Moran's I index

Year	Moran's I	Z(I)	Year	Moran's I	Z(I)
2009	0.047***(0.007)	2.464	2015	0.032**(0.022)	2.023
2010	0.045***(0.008)	2.408	2016	0.037**(0.015)	2.172
2011	0.036**(0.017)	2.120	2017	0.037**(0.015)	2.173
2012	0.038**(0.014)	2.202	2018	0.022**(0.042)	1.731
2013	0.031**(0.024)	1.974	2019	0.028**(0.025)	1.909
2014	0.036**(0.017)	2.129			

Note: P values in brackets, *, **, *** indicate significant at the significance level of 10%, 5%, and 1%, respectively.

5.3. Testing of spatial econometric model

Before the regression analysis of the spatial panel model, it is necessary to test the spatial metrology model, and the results are shown in Table 4. In the first step, the results of LM test and robust LM test show that both LM test and robust LM test of SLM and SEM models reject the null hypothesis. According to Jiang Lei's conclusion, if SLM model is adopted for empirical analysis, it is better to expand to SDM model. At the same time, LM test can not judge the applicability of SDM model, so this paper continues to conduct LR test and Wald test to determine whether SDM model can be degraded into SEM model or SLM model.

Before the LR test, Hausmann test is required to determine whether the model is a fixed effects model or a random effects model. It should be noted that the general panel model is usually used to regression the fixed effect model and the random effect model respectively, and then the two results are tested by Hausmann test. Federico Belotti pointed out that this method is wrong to be applied to the spatial panel model in the environment of Stata, and the Hausmann statistic does not meet its asymptotic hypothesis at this time. Therefore, this paper makes reference to Federico Belotti's practice to conduct Hausmann test on the model. The result shows the fixed effect of selection.

As shown in the LR test, in terms of model selection, both LR test and Wald test reject the null hypothesis, that is, SDM model cannot be simplified. The LR test results reject the null hypothesis in terms of controlling for individual, time or bidirectional fixed effects, and the LR test results for time fixed effects reject the null hypothesis only at the significance level of 10%.

Combined with the analysis of test results, this paper

selects SDM bidirectional fixed effect model and SDM time fixed effect model for regression and uses Robust and robust standard error regression to control the impact of heteroscedasticity on regression results. Among them, SDM time fixed effect model has better regression effect. In this paper, only the results of the time-fixed effect model are reported and analyzed.

Table 4. Test results of spatial panel model

Statistic	P-value	Statistic	P-value
LM-error	0.077*	LR-spatial	0.000***
RLM-error	0.010***	LR-SEM	0.000***
LM-lag	0.004***	LR-SLM	0.000***
RLM-lag	0.001***	Wald-SLM	0.000***
Huassman	0.000***	Wald-SEM	0.000***
LR-time	0.053*		

5.4. Spatial Durbin model regression results

The regression results of the spatial Durbin model are shown in Table 5. The R² is 94.70%, indicating that the overall goodness of fit of the model is good. Log-likelihood is 806.303. The three independent variables selected in this paper, INNO, ECON and ENVI, can better explain the dependent variable IEE, so the model has certain applicability. The spatial autoregressive coefficient rho passed the significance test of 1% with a high significance level, which once again proved that the variables in the model had spatial correlation.

It is worth noting that the spatial autoregressive coefficient rho is -0.708, which means that the growth of the regional IEE coupling coordination degree has a negative effect on the regional IEE coupling coordination degree, and the regional IEE system coupling degree has a polarization effect. This seems to be in conflict with the previous test result of the global Molan index, "IEE coupling coordination degree has a positive spatial correlation", so this paper calculates the results of the spatial autoregressive coefficient of the SAR model, and finds that the rho in the SAR model is positive. Firstly, the global Moran index can only explain the phenomenon of significant spatial clustering of the coupling coordination degree of IEE system, but can not explain the reason. Secondly, SDM model is a general form of SAR model, which adds the spatial lag term of the independent variable on the basis of SAR model. After the spatial lag term of the independent variable is included, the symbol of the spatial autoregressive coefficient changes precisely to explain the phenomenon: The coupling coordination degree of IEE has a polarization effect in space, which will inhibit the coordinated development of IEE in surrounding cities. It is the three subsystems of INNO, ECON and ENVI that really promote the clustering of the coupling coordination degree of IEE in space.

Sage and Pace (2009) proposed that when the coefficient of the spatial lag term of the explained variable is significantly non-zero, there will be systematic bias in using the coefficient of the spatial Durbin model to measure the spillover effect of economic growth [30], and it is inappropriate to directly analyze the regression results of the Durbin model, so this paper only analyzes the decomposition results of the spatial Durbin model.

It can be seen from the results in Table 5 that among the direct effects of each variable, the three subsystems all pass the significance level test of 1%, and the coefficients are all positive, indicating that the improvement of the coupling

coordination degree of the three subsystems has a significant positive promotion effect on the coupling and coordination development of the IEE system in the region, among which the positive promotion effect of the industry, university and research is the most obvious, and its coefficient is 0.405. Much higher than the other two subsystems; Among the indirect effects of each variable, only the regression coefficient of the industry-university-research system is positive, indicating that the improvement of the coupling coordination degree of the industry-university-research system has a significant positive promoting effect on the coupling coordination degree of the IEE system in the neighboring region, while the improvement of the coupling coordination degree of the regional economic and ecological environment system will inhibit the coupling and coordination development of the IEE system in the neighboring region. Comparing the absolute regression coefficients of the three subsystems in the direct effect, like the direct effect, the industry-university-research system still plays the most prominent role in the IEE system. Among the total effects of various variables, regional economy and ecological environment do not have statistically significant effects on IEE system. In the spatial Durbin model, the total effect represents the sum of direct effects and indirect effects, and its display significance is the average impact of a regional explanatory variable on explained variables in all regions. The regression coefficients of direct and indirect effects of regional economy and ecological environment are negative, which may be the reason why the regression coefficients of these two explanatory variables are not significant in the total effects. In addition, by comparing the direct effect, indirect effect and total effect, it can be found that the spatial spillover effect of the three subsystems is greater than the local impact.

Table 5. Test results of spatial panel model

Variable	Direct effect	Indirect effect	Total effect
INNO	0.405*** (0.000)	0.678*** (0.000)	1.073*** (0.000)
ECON	0.277*** (0.001)	-0.446*** (0.004)	-0.169 (0.314)
ENVI	0.246*** (0.004)	-0.388*** (0.001)	-0.142 (0.260)
Rho-sdm		-0.708***	
Rho-sar		0.357***	
R ²		0.947	
Log-likelihood		806.303	

6. Research Conclusion and Policy Recommendation

Based on the coupling model and the spatial Durbin model, this paper analyzes the provincial panel data of China from 2009 to 2019. First, the coupling model is used to obtain the spatio-temporal evolution of the coupling coordination degree of IEE system and its subsystems in 30 provinces and cities and four regions in China. Then the global Moran index is used to calculate the spatial clustering phenomenon of the coupling coordination degree of IEE system in China. At last, the paper analyzes the reason of the spatial clustering phenomenon of the coupling coordination degree of IEE system by using the spatial Durbin model, and the spatial influence of each subsystem on it. Based on the above results

and analysis, this paper analyzes the following five main conclusions and gives suggestions.

First, the coupling coordination degree of China's IEE system presents a distribution of "high coupling degree and low coupling coordination degree" on the whole, which indicates that there is a strong relationship among industry, university and research, economy and ecology, but this interaction is more restricted in 2009-2019. The spatial distribution of the coupling coordination degree of IEE system in China is "high in the east, flat in the middle and northeast, and low in the west", which indicates the basic national conditions of unbalanced and inadequate regional development in China. The coupling coordination degree of IEE system in China shows the distribution of "high regional economic system and low industry-university-research system" in the internal subsystem. According to the average coupling coordination degree from 2009 to 2019, 83% of the regions belong to the backward type of industry-university-research system. Scientific and technological innovation, ecological environment and economic development are interdependent and interact with each other, and the spatial imbalance and insufficiency of the three lead to more mutual constraints in their development process, ignoring the environment and science and technology and only focusing on the speed of economic development, which will have to slow down the speed of economic development in the future due to the constraints of the ecological environment and scientific and technological level.

Second, the coupling coordination degree of eco-environmental systems in the four major regions of China fluctuated from 2009 to 2019.

Third, the coupling coordination degree of IEE system has a polarization effect in space, and the improvement of the coupling coordination degree of IEE system in a certain region will attract favorable factors to the local area, which is not conducive to the coordinated development of IEE in the surrounding region. The development of the industry-university-research innovation system has a spatial diffusion effect, while the development of the regional economy and the optimization of the ecosystem have a polarization effect on the neighboring regions.

Fourth, the coordinated development of industry-university-research innovation system has the most obvious positive effect on the improvement of the coupling coordination degree of IEE system. There may be the following reasons: On the one hand, for the developed regions, the innovation system of industry, university and research as a key link to improve our country's science and technology innovation system mechanism, with the quality change, efficiency change and dynamic change of economic development in the new era of continuous promotion, its role in the coupled and coordinated development of IEE system becomes increasingly prominent; On the other hand, for underdeveloped areas, the innovation system of industry, university and research is equivalent to a short board compared with the regional economic and ecological environment systems, and has a "wooden barrel effect" in the process of promoting the coupling and coordinated development of IEE system. Promoting the development of industry, university and research innovation system can improve the "capacity ceiling" of IEE system most efficiently.

Based on the above findings, in order to promote the further coordinated development of China's industry-university-research innovation system, regional economy and ecological

environment, this paper gives the following suggestions: First, for regional economic development, attention should be paid to the stability, balance and sustainability of economic development. Although China's current ecological environment and industry-university-research innovation system are relatively backward, ensuring sustained economic growth is still the primary position, and the adverse impact brought by the instability of economic growth is inestimable. Second, for the ecological environment, on the whole, the coupling degree of China's ecological environment system has been fluctuating up and down, with no obvious upward or downward trend. The green economic development mode based on the premise of not sacrificing the environment should be vigorously advocated. From the individual point of view, the regions where the coupling degree of the ecological environment system is stable and rising should continue to be maintained. The policy focus should be placed on the regions where the coupling coordination degree of ecological and environmental systems has decreased significantly, especially Beijing and Tianjin, where the coupling coordination degree of ecological systems in 2019 decreased by 0.049 and 0.041 respectively compared with 2009, and the other regions are basically in a stable state. Thirdly, as for the innovation system of industry-university-research, it can be seen from the above conclusions that the current industry-university-research system is a weak board in IEE system, which greatly restricts the coordinated development of the three. On the other hand, investment in the innovation system of industry-university-research can most effectively improve the "capacity ceiling" of IEE system, and the innovation system of industry-university-research is the only one with polarization effect among the three. The spillover effect of promoting the development of the industry-university-research innovation system can also drive the development of the surrounding areas. For the industry-university-research innovation system, full attention should be paid to the dominant position of enterprises in all innovative individuals, because enterprises directly face the market and can most effectively promote the transformation of innovation results. To promote the convergence of various elements to enterprises and give full play to the innovation vitality of enterprises, on the other hand, attention should also be paid to the construction of a resource service platform for industry-university-research collaborative innovation. Existing

research results have proved that each subject in the innovation system also has a strong knowledge spillover effect, and the construction of an innovation platform can effectively prevent the phenomenon of information asymmetry and waste of innovation resource.

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