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Coupling Coordination between University Scientific & Technological Innovation and Sustainable Economic Development in China

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Abstract: Coupling development between university science and technology (S&T) innovation and economy is an objective requirement for achieving sustainable economic and social development. The main goal of this paper is to explore the situation of the coupling coordination relationship between the two systems, i.e., university S&T innovation and sustainable economic development in China. It also hopes to provide a reference for promoting the coordinated development between the two. This paper constructs the evaluation index system of university S&T innovation and sustainable economic development separately and evaluates the indicators of university S&T innovation and sustainable economic development in 30 provincial regions in China from 2011 to 2020. On this basis, a coupling coordination degree model is constructed to evaluate the coupling coordination degree of university S&T innovation and sustainable economic development. Accordingly, this paper puts forward suggestions for promoting the coordinated development between university S&T innovation and sustainable economic development.

Keywords: university S&T innovation; sustainable economic development; coupling coordination

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1. Introduction

The growth pole theory put forward by Perroux points out that the main driving force of regional economic development is technological progress and innovation [1]. As an important force of original innovation in basic research and high-tech fields, universities provide powerful energy for the progress of S&T and the sustainable development of society [2]. Along with the in-depth development of the economy and society, promoting the deep integration of university S&T innovation and economy is not only a practical need based on sustainable development but also an important support to promote the high-quality development of society. Therefore, it is an urgent need to properly handle the coordination between the two systems, i.e., university S&T innovation and sustainable economic development, so as to promote the coordination between the two and then form a virtuous and coordinated cycle mechanism of S&T and economy.

Before improving the coordination between university S&T innovation and sustainable economic development, it is necessary to clarify the current situation of the coordination between the two systems. This paper focuses on the coordination relationship in Chinese provincial regions. What is the relationship between the two systems in reality? Are there any differences in coupling coordination between regions? This paper aims to clarify the situation of the coupling coordination relationship between the two systems in China from the perspective of time evolution and spatial pattern. It aims to provide a reference for promoting the coordinated development between the two systems.

2. Literature Reviewed

In recent years, scholars have conducted in-depth theoretical discussions and empirical studies on the impact between S&T innovation and economic development and achieved fruitful research results. Scholars mostly focused on the one-way effect of S&T innovation on economic development. Cheng et al. believed that S&T innovation is the core power of economic development and proved that various elements of S&T play a powerful role in promoting regional economic development through empirical analysis [3]. Salvatore verifies the contribution of S&T innovation to sustainable economic development based on the empirical data of UNESCO [4]. Sefer and Ercan proved the positive effect of S&T innovation on economic growth and competitiveness [5].

However, it is not comprehensive to consider the one-way effect of the S&T system on the economic system. Some scholars further researched the feedback or interaction of economic development on the S&T innovation system. Zanello et al. believed that the dynamic relationship between technological innovation and the local geographical environment, economic system, and political and legal system is the key condition for the success of regional economic development [6]. Maradana et al. investigated the long-term relationship between innovation and per capita economic growth in 19 European countries from 1989 to 2014 and found that there was a two-way causal relationship between innovation and per capita economic growth [7]. Liu and Xia established an indicator system with R&D investment, technological innovation and economic growth as research variables to discuss the two-way interaction between technological innovation and economic and social development [8].

As one of the three major S&T innovation forces [9], the impact of university S&T innovation on economic development has been given more prominence by scholars. Goldstein et al. analyzed the contribution of universities to regional economic development through empirical evidence and believed that university S&T innovation activities promote economic development by generating knowledge spillover effects [10]. Kruss et al. studied the impact of higher education on economic development and stressed the importance of considering the intersection of spatial dimensions [11]. Smith and Bagchi-Sen pointed out that the "aggregation" behavior between universities and regional enterprises plays an important influence, such as business training and innovation investment [12]. Wang et al. used the C-D production function model and entropy value method to measure the rate of S&T progress and the contribution of universities in Liaoning Province of China and concluded that the investment of university research funds plays an important role in regional economic development [13]. Li empirically studied the influence of university S&T innovation on regional economic development in 19 sub-provincial cities in China from 2008 to 2017 [14]. Wang et al. investigated the cross-regional flow of innovation capability factors of universities in China's coastal provinces and cities from 2005 to 2017 and proved the innovation ability of universities has an obvious spatial spillover positive effect on regional economic growth [15]. Cheng et al. studied the impact of the university-industry cooperation policy (UIC policy) on knowledge innovation and achievement transformation in universities and pointed out that cooperation between enterprise and universities can play an important role in economic transformation and development [16]. Li concluded that university S&T innovation could improve enterprise production efficiency, optimize the industrial structure, and promote energy saving and emission reduction [17]. In addition, Zhang et al. used a panel quantile spatial autoregressive model to empirically analyze the impact of S&T innovation in higher education institutions on regional economic development [18].

By ordering the existing research results, it can be found that the relevant research mostly focuses on the two-way relationship between S&T innovation and economic development at the macro level. In the existing literature with universities' S&T innovation as the research object, most of the existing research results focus on the effect of university S&T innovation in promoting economic development while ignoring the coupling coordination between the two. Few scholars research from the perspective of the two-way interaction between university S&T innovation and sustainable economic development, and few pay attention to the long-term changes between the two. Based on the existing research, with entropy value method, coupled coordination model and multiple regression, this paper analyses the time evolution and spatial pattern of coupling coordination between university S&T innovation and sustainable economic development in 30 provincial-level regions of China (excluding Tibet, Hong Kong, Macao and Taiwan) from 2011 to 2020.

3. Theoretical Analysis of the Coupling Mechanism

Coupling is originally a concept of physics, which refers to the phenomenon that two and more systems or forms of motion interact with each other in various forms and are closely related to each other [19]. Based on the premise that there is some form of association between various coupled subjects, coupling is used to analyze the dynamic relationship between multiple systems with connections [20]. University S&T innovation and sustainable economic development are closely related and have an interactive relationship, which can generate a positive synergistic amplification effect. University S&T innovation includes three parts: innovation inputs, innovation outputs and innovation environment. It affects sustainable economic development, which is specifically reflected in the impact on economic scale, economic structure, and economic quality. According to the two-way interaction relationship, the coupling mechanism diagram between university S&T innovation and sustainable economic development is constructed as shown in Figure 1.

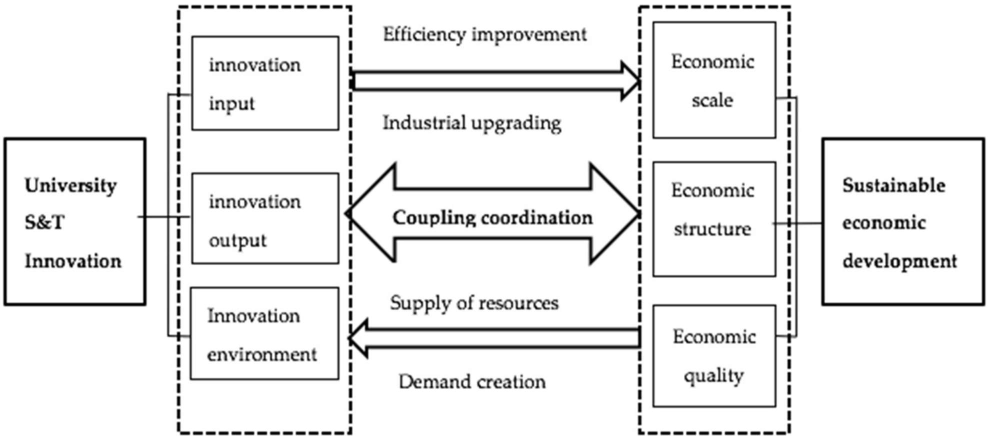

Figure 1. The coupling mechanism between university S&T innovation and sustainable economic development.

3.1. University S&T Innovation Promotes Sustainable Economic Development

The basic factors of sustainable economic growth are labor, capital, and scientific and technological progress. According to the Cobb-Douglas function that shows the dependency between capital input, labor input and output under certain production technology conditions, technology is an important factor that determines the level of economic growth [21]. In China, universities are an important part of the S&T system, and university scientific and technological innovation is also one of the important sources of economic growth. University S&T innovation acts on the optimization and upgrading of industries and the enhancement of economic benefits. Through the continuous diffusion of knowledge, information and technical resources, university S&T innovation has prompted corresponding changes in the human resource, production factors, production processes and production organization in the production field, and all factors in the production field will be recombined accordingly, further widening the space of production activities. Along with the generation and application of new technologies and new products, it accelerates the pace of innovation diffusion and promotes industrial innovation, which in turn changes the original factors of production, promotes the renewal of technology and realizes the transformation and upgrading of industry. Due to the continuous improvement of production factors, the efficiency of social labor productivity and resource allocation has been significantly improved, which not only increases the output of unit factors and the added value of resources but also changes the mode of economic growth, accelerates the transformation of economic growth from rough operation to intensive operation, and realizes the overall improvement of total factor productivity, labor productivity and the contribution rate of human capital.

3.2. Sustainable Economic Development Supports University S&T Innovation

The effective implementation of S&T innovation activities of universities is inseparable from the resource guarantee provided by sustainable economic development. In addition, sustainable economic development has produced a demand-pulling effect on the in-depth development of university S&T innovation and has also created a good innovation environment for innovation. Firstly, university S&T innovation needs to invest a lot of resources, especially financial support. The development of the economy means the increase of social wealth, which provides sufficient research funds for universities to carry out scientific and technological innovation activities. At the same time, the level of sustainable economic development directly affects the level of running and teaching quality of universities and thus enhances the level of scientific and technological innovation of universities, especially for new research universities, the importance of sufficient funds to strengthen the construction of basic disciplines and basic research is self-evident. Secondly, strong regional economic strength can attract all kinds of scientific and technological talents, thus optimizing the structure of the educational faculty and strengthening the scientific and technological talents in universities. Thirdly, the development of the economy will stimulate people's material and spiritual needs and expand market space, which will also stimulate university S&T personnel to carry out technical innovation and invention. Finally, sustainable economic development creates a good environment for scientific and technological innovation in universities. Sustainable economic development can promote the exchange of culture and the dissemination of knowledge, thus enhancing people's innovation consciousness and improving the comprehensive quality of the social groups to create a good operating environment for scientific and technological innovation in universities

4. Index System and Research Methods

4.1. The Construction of the Index System

The research on the coupling coordination of university S&T innovation and sustainable economic development must be based on the comprehensive evaluation of the two. According to the basic connotations and main ingredients, we followed the scientific, systematic principle of comparability and the availability of data in reference to the indicators designing of Xiao [22] and Liu [23], combined with the actual development situation in recent years in China, this study separately constructs the evaluation index system of university S&T innovation and sustainable economic development, as shown in Table 1. According to the evaluation system of university S&T innovation, this paper constructs 9 secondary indicators from 3 primary indicators: innovation inputs, innovation output and innovation environment. The evaluation index system of sustainable economic development includes 9 secondary indicators from 3 primary indicators: economic scale, economic structure and economic quality.

Table 1. Evaluation index system.

Subsystem	Primary Indicators	The Secondary Indicators	Index Attribute	Order Parameter
University S&T innovation	Innovation inputs	Research staff (person)	+	X_{11}
		S&T funds investment (1000 yuan)	+	X_{12}
		Full-time R&D staff (person year)	+	X_{13}
	Innovation outputs	Number of achievement applications and S&T service projects (items)	+	X_{14}
		Number of academic papers (articles)	+	X_{15}
		Number of patents granted (item)	+	X_{16}

Table 1. *Cont.*

Subsystem	Primary Indicators	The Secondary Indicators	Index Attribute	Order Parameter
University S&T innovation	innovation environment	Number of universities (units)	+	X_{17}
		Number of R&D institutions in universities (units)	+	X_{18}
		Proportion of illiterate population over 15 years (%)	-	X_{19}
Sustainable economic development	Economic scale	Gross Regional Product (100 million RMB yuan)	+	X_{21}
		Regional fiscal revenue (100 million RMB yuan)	+	X_{22}
		Total retail sales of consumer goods (100 million RMB yuan)	+	X_{23}
	Economic structure	Proportion of tertiary industry in GDP (%)	+	X_{24}
		Proportion of employees in the Tertiary Industry in the Employed Population (%)	+	X_{25}
		R&D investment intensity (%)	+	X_{26}
	Economic quality	Per capita gross regional product (RMB Yuan)	+	X_{27}
		Per capita disposable income of urban residents (RMB Yuan)	+	X_{28}
		Social labor productivity (10 thousand RMB yuan/person)	+	X_{29}

This paper takes 30 provincial regions (excluding Tibet, Hong Kong, Macao and Taiwan because of many missing data) from 2011 to 2020 as the research objects. Among them, the data are from "The Compilation of S&T Statistics of Institutions of Higher Learning," "China Education Statistical Yearbook," "China Science and Technology Statistical Yearbook," and "China Statistical Yearbook." It should be pointed out that the intensity of R&D investment is represented by the ratio of R&D investment to GDP, and the social labor productivity is represented by the ratio of regional GDP to the total number of employed people.

4.2. Research Methods

4.2.1. Entropy Value Method

As an objective weighting method, the entropy value method mainly obtains the weight coefficient by calculating the index of information entropy to judge the degree of data dispersion [24] and then realizes the comprehensive evaluation of the index system. The specific calculation steps are as follows:

(1) Standardize the original data

For positive indicators:

$$x'_{ij} = \left(x_{ij} - max\{x_{ij}\}\right) / \left(max\{x_{ij}\} - min\{x_{ij}\}\right) \tag{1}$$

For the negative indicators:

$$x'_{ij} = \left(max\{x_{ij}\} - x_{ij}\right) / \left(max\{x_{ij}\} - min\{x_{ij}\}\right) \tag{2}$$

x'_{ij}(i = 1, 2; j = 1, 2, 3 ... 9) is the jth index of the i system.

Since the index will have no value after standardization processing, the logarithm of the entropy value cannot be taken in the calculation. Therefore, in order to ensure the rationality and usability of the data, the standardized value of each index was shifted by 0.01 units. Namely $x''_{ij} = x'_{ij} + 0.01$.

(2) The proportion P_{ij} of the jth index in subsystem i is calculated, and the formula is $p_{ij} = x_{ij} / \sum_{i=1}^{m} x_{ij}$, m is the number of evaluation samples, namely 30.

(3) The jth index entropy value, e_j, is calculated, and the formula [25] is

$$e_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} P_{ij} \ln(P_{ij}) \tag{3}$$

(4) To calculate the difference coefficient g_j of the jth index, the formula is

$$g_j = 1 - e_j \tag{4}$$

(5) Calculate the weight w_j of the jth index, whose formula is

$$w_j = g_j / \sum_{j=1}^{m} g_j \tag{5}$$

n is the number of secondary indicators of the subsystem.

(6) The composite index U of the 2 subsystems in each year from 2011 to 2020 is calculated, and the formula is

$$U = \sum_{i=1}^{n} w_j x''_{ij} \tag{6}$$

4.2.2. Coupling Coordination Model

According to the basic principle of coupling coordination and on the basis of the existing research [26], the coupling coordination degree model of university S&T innovation and sustainable economic development is constructed to measure the coordination degree of interaction coupling between the 2 subsystems.

The coupling degree C of the 2 subsystems is calculated, and the formula is:

$$C = 2\sqrt{\frac{U_1 \times U_2}{(U_1 + U_2)^2}} \tag{7}$$

In view of the staggered and unbalanced characteristics of university S&T innovation and sustainable economic development, the coupling degree C is difficult to fully reflect the true level of coupling coordination under some conditions. Therefore, the coupling coordination degree model is introduced:

$$D = \sqrt{C \times T} \tag{8}$$

$$T = \alpha U_1 + \beta U_2 \tag{9}$$

where C and $D \in [0, 1]$, the closer the values of C and D are to 1, the higher the coupling level and the better the coupling coordination between the 2 systems. T is the comprehensive coordination index of the two systems, which reflects the contribution of the overall level of university S&T innovation and sustainable economic development to the coupling coordination degree. α and β are undetermined coefficients, and $\alpha + \beta = 1$. In view of university S&T innovation and sustainable economic development are equally important, $\alpha = \beta = 0.5$.

According to the numerical value range of the coupling coordination degree and the existing research [27], the coupling coordination degree is divided into 5 grades, as shown in Table 2.

Table 2. Classification standard of coupling coordination degree.

Degree of Coupling Coordination	Grade
$0 \le D \le 0.2$	Severe maladjustment
$0.2 < D \le 0.4$	On the verge of maladjustment
$0.4 < D \le 0.6$	Primary coordination
$0.6 < D \le 0.8$	Good coordination
$0.8 < D \le 1$	High-quality coordination

5. Empirical Results and Analysis

5.1. Evaluation of University S&T Innovation and Sustainable Economic Development

The entropy value method is used to calculate the evaluation value of university S&T innovation and sustainable economic development of 30 provincial regions in China from 2011 to 2020. The evaluation values in most of the provinces indicate stability and slight increases. It is worth noting that the COVID-19 epidemic that occurred at the end of 2019 has caused a great impact on China's economic and social development. In 2020, the evaluation values of university S&T innovation and sustainable economic development decreased to varying degrees.

5.1.1. Evaluation of University S&T Innovation

According to the entropy method introduced in Section 4.2.1, the evaluation values (Figure 2) of university S&T innovation are calculated through Formulas (1)–(6). The values of Jiangsu, Beijing, and Shanghai ranked in the top three, reflecting the strong innovation ability of universities. In addition, Zhejiang, Shandong, Hubei, and other places have higher evaluation values and show an increasing trend. The reason is that the plentiful scientific and technological resources of universities and the perfect S&T innovation system in the regions have played an important role. For example, there are 31 "double first-class" universities in Beijing, 15 in Shanghai and 13 in Nanjing, far more than in other regions. Outstanding talents, innovation teams, and sufficient R&D funds provide continuous vitality for university S&T innovation. However, due to the constraints of geographical location and the weak scientific research foundation of universities in Qinghai, Ningxia, Xinjiang, and other places in the western region, the evaluation value is always at a lower level, which is significantly different from the developed coastal areas in the east. Meanwhile, the evaluation value in the northeast region has a decreasing trend, while Shanxi, Henan, Jiangxi, Hunan and etc., in the central region show a steadily increasing trend.

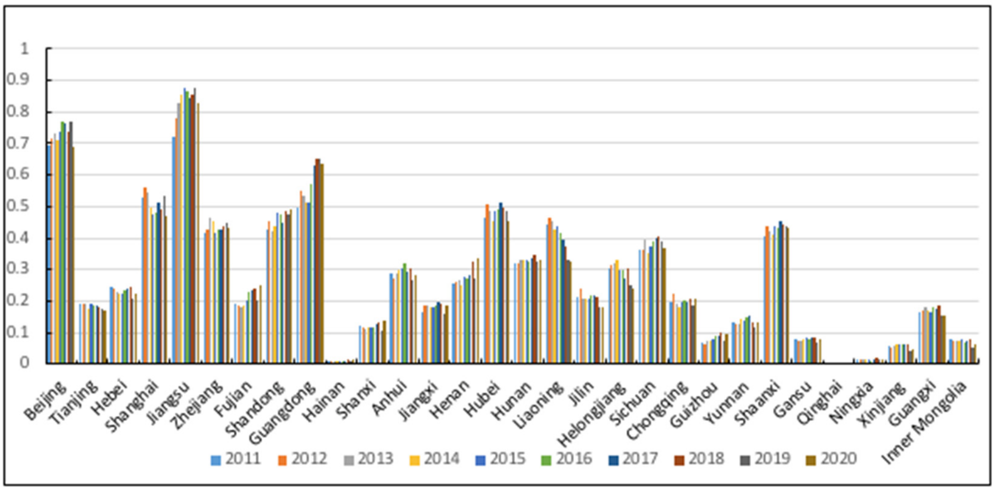

Figure 2. The evaluation value of university S&T innovation in provincial regions.

5.1.2. Evaluation of Sustainable Economic Development

According to the entropy method introduced in Section 4.2.1, the evaluation values (Figure 3) of sustainable economic development are calculated through Formulas (1)–(6). The evaluation value of Beijing, Shanghai, Jiangsu, Guangdong, and Zhejiang are at the forefront of the country. Most regions show stable development, which is in line with the driving force of development being shifted from investment to innovation. Under the guidance of the economic development strategy system such as Beijing-Tianjin-Hebei Cooperative Development, Yangtze River Economic Belt Development, Yangtze River Delta Economic Circle and the construction of the Chengdu-Chongqing Region Twin Cities Economic Circle, Chinese economic strength has continued to improve. Only Tianjin, Shanxi, Inner Mongolia, Guangxi, Ningxia, and Northeast China are affected by the extensive production mode and the relatively slow upgrading of industrial structure, which makes the evaluation value decline slightly, resulting in a relatively backward transformation and upgrading of economic structure. From the perspective of spatial layout, there is a wide gap between different regions, especially between the eastern coastal areas and the remote western areas. In addition, the evaluation value of the central region has shown a trend of the steady growth of sustainable economic development in recent years.

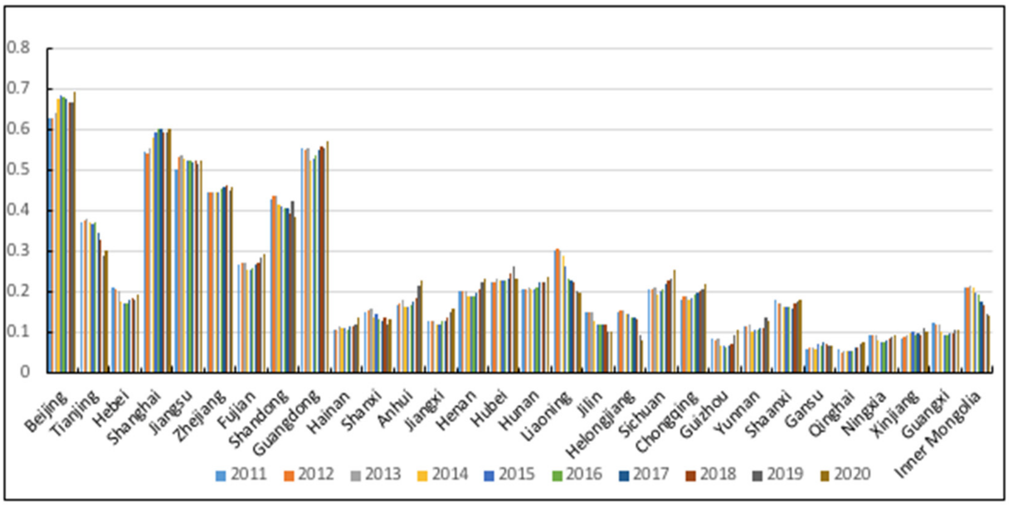

Figure 3. The evaluation value of sustainable economic development in provincial regions.

5.2. Evolution Characteristics of Coupling Coordination

Based on the evaluation value of university S&T innovation and sustainable economic development, the coupling coordination model, which is introduced in Section 4.2.2, is applied. The coupling coordination degree of the two subsystems of 30 provincial regions in China from 2011–2020 is measured through Formula (7)–(9). The results are shown in Table 3.

Table 3. Coupling coordination degree of university S&T innovation and sustainable economic development in provincial regions (2011–2020).

Province	Years										Average
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
					The Eastern Region						
Beijing	0.814	0.820	0.827	0.832	0.843	0.850	0.849	0.838	0.848	0.831	0.835
Tianjin	0.517	0.517	0.521	0.506	0.515	0.512	0.504	0.492	0.475	0.476	0.504
Hebei	0.475	0.472	0.466	0.446	0.443	0.447	0.453	0.462	0.439	0.455	0.456
Shanghai	0.732	0.744	0.742	0.734	0.728	0.733	0.745	0.735	0.751	0.729	0.737
Jiangsu	0.776	0.803	0.817	0.819	0.824	0.821	0.815	0.819	0.819	0.813	0.813

Table 3. *Cont.*

Province	Years										Average
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
Zhejiang	0.656	0.659	0.675	0.669	0.657	0.664	0.666	0.672	0.671	0.669	0.666
Fujian	0.474	0.473	0.470	0.465	0.477	0.495	0.500	0.507	0.489	0.521	0.487
Shandong	0.655	0.666	0.654	0.652	0.666	0.663	0.653	0.664	0.670	0.659	0.660
Guangdong	0.725	0.742	0.739	0.719	0.721	0.744	0.767	0.776	0.777	0.776	0.749
Hainan	0.181	0.181	0.184	0.166	0.169	0.177	0.176	0.178	0.191	0.208	0.181
Average	0.601	0.608	0.609	0.601	0.604	0.611	0.613	0.614	0.613	0.614	0.609
The Central Region											
Shanxi	0.367	0.365	0.363	0.354	0.359	0.353	0.358	0.367	0.334	0.366	0.358
Anhui	0.469	0.466	0.477	0.467	0.472	0.482	0.476	0.486	0.488	0.504	0.479
Jiangxi	0.381	0.392	0.392	0.381	0.384	0.393	0.396	0.400	0.391	0.415	0.392
Henan	0.475	0.479	0.481	0.465	0.478	0.476	0.486	0.512	0.497	0.527	0.488
Hubei	0.568	0.582	0.578	0.566	0.577	0.580	0.588	0.585	0.597	0.571	0.579
Hunan	0.506	0.506	0.514	0.510	0.510	0.511	0.523	0.529	0.519	0.529	0.516
Average	0.461	0.465	0.467	0.457	0.463	0.466	0.471	0.480	0.471	0.485	0.469
The Northeastern Region											
Liaoning	0.605	0.613	0.609	0.595	0.581	0.557	0.547	0.537	0.507	0.503	0.565
Jilin	0.424	0.436	0.418	0.404	0.398	0.404	0.402	0.398	0.369	0.366	0.402
Heilongjiang	0.461	0.470	0.472	0.469	0.455	0.448	0.439	0.454	0.391	0.373	0.443
Average	0.496	0.506	0.500	0.489	0.478	0.470	0.463	0.463	0.422	0.414	0.470
The Western Region											
Sichuan	0.521	0.523	0.536	0.513	0.524	0.533	0.544	0.548	0.549	0.552	0.534
Chongqing	0.434	0.453	0.437	0.426	0.437	0.443	0.443	0.451	0.442	0.462	0.443
Guizhou	0.277	0.267	0.279	0.261	0.269	0.273	0.279	0.291	0.285	0.315	0.280
Yunnan	0.350	0.348	0.351	0.347	0.346	0.353	0.360	0.347	0.355	0.361	0.352
Shaanxi	0.518	0.524	0.519	0.508	0.515	0.513	0.519	0.519	0.527	0.527	0.519
Gansu	0.261	0.260	0.263	0.262	0.275	0.272	0.279	0.279	0.260	0.269	0.268
Qinghai	0.114	0.107	0.091	0.112	0.109	0.105	0.102	0.102	0.106	0.107	0.106
Ningxia	0.192	0.192	0.195	0.174	0.173	0.163	0.179	0.189	0.191	0.196	0.184
Sinkiang	0.261	0.262	0.273	0.278	0.280	0.278	0.278	0.279	0.259	0.266	0.272
Guangxi	0.377	0.377	0.382	0.363	0.353	0.359	0.361	0.367	0.354	0.357	0.365
Inner Mongol	0.356	0.355	0.352	0.352	0.351	0.339	0.340	0.334	0.295	0.309	0.338
Average	0.333	0.333	0.334	0.327	0.330	0.330	0.335	0.337	0.329	0.338	0.333

In general, the coupling coordination degree between university S&T innovation and sustainable economic development in most regions show a steady increase and gradually stabilize, but the growth rate is low. It indicates that university S&T innovation and sustainable economic development in China are developing in a more coordinated direction, but the speed of coordinated development is relatively slow, and the coupling coordination in most regions should be improved. The coupling coordination in the central region has the largest increase of the four regions, from 0.461 in 2011 to 0.485 in 2020. However, in Northeast China, the trend is downward.

5.3. Spatial Pattern Distribution of Coupling Coordination

ArcGIS10.2 software is used to visually display the average value of the coupling coordination degree from 2011 to 2020 in the form of a regional map, as shown in Figure 4. From the perspective of spatial layout, there are obvious regional differences in the degree of coupling and coordination in China. The overall unbalanced trend of "high coupling degree in the eastern and southern region, low coupling degree in the western and northern region" is shown, and the spatial stratification of coupling coordination degree gradually decreases from coastal to inland areas.

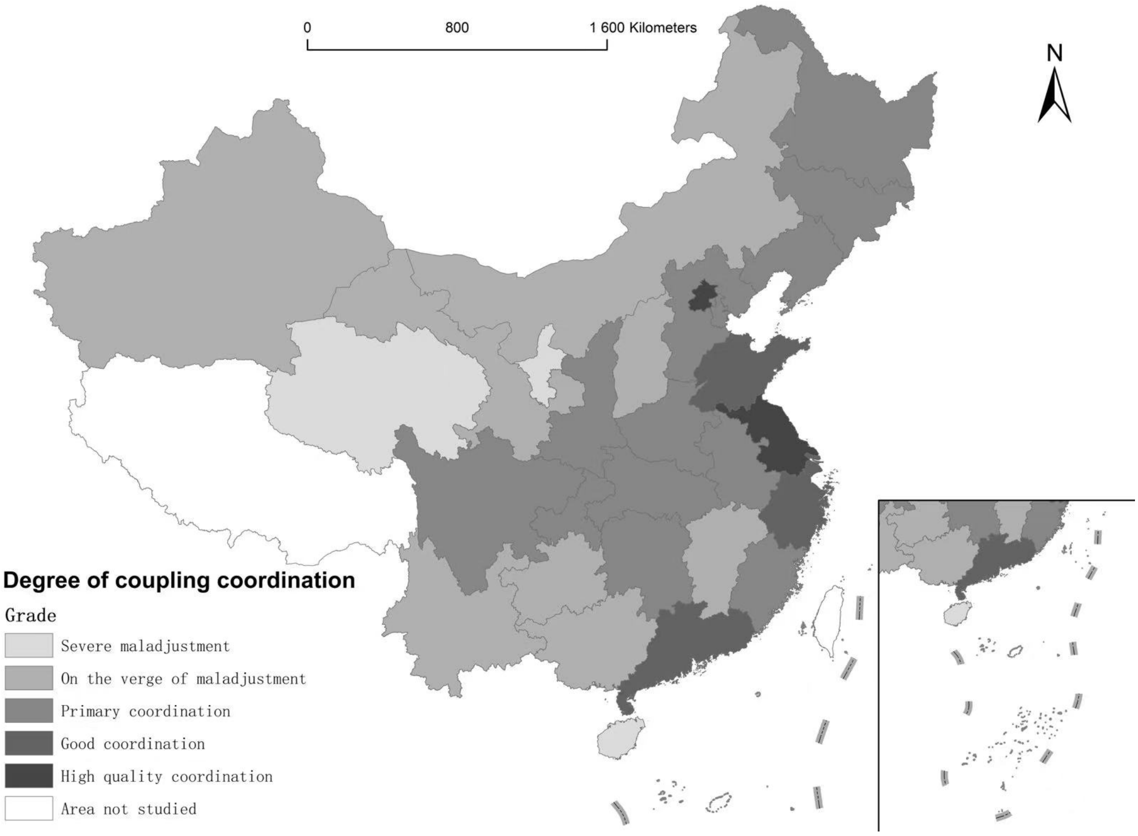

Figure 4. Spatial distribution pattern of the average coupling coordination degree in provinces of China from 2011 to 2020.

Taking the average value of each region from 2011 to 2020 as an example, the coupling coordination degree of Beijing, Jiangsu, Guangdong, and Shanghai ranks the top in the country, among which Beijing and Jiangsu are in the stage of high-quality coordination. Beijing, as the capital of China, is the national center of S&T innovation and the region with the densest scientific, educational, intellectual, and human resources in China. Relying on its unique geographical advantages, strong economic strength, and superior scientific and technological innovation foundations, the coupling coordination degree of Beijing has always ranked first in the country. With the dual advantages of real economic and industry research, Jiangsu has been committed to building a strong province in S&T and implementing various plans for sustainable development based on the in-depth implementation of the innovation-driven development strategy, and its coupling degree has been following that of Beijing. With the dual advantages of real economic and industry research, Guangdong, as a major economic province in China, has been strengthening the comprehensive strength of S&T in universities, and its coupling coordination degree has been in a good coordination stage and maintained a steady increase. Shanghai is the most economically developed region in China and also a region with concentrated higher education resources. In recent years, the construction of the S&T innovation system in universities has been accelerated, the S&T innovation capacity of universities has been enhanced continuously, and its coupling coordination degree has been maintained at a good coupling level. Besides, although the coupling coordination degree of Fujian, Hainan and other places in the eastern region is lower, it has been maintaining a good trend of a steady increase in the past 10 years.

The coupling coordination degree of the central region (except Shanxi) maintains an upward trend. Driven by the implementation of the strategy for the rise of the central region, the strength of science and education has been significantly enhanced, and the coordinated development of the central region is gaining momentum. Except for Shanxi, the coupling coordination degree of the central region in 2020 is above 0.4, and the situation of coordinated development between university S&T innovation and sustainable economic development is initially formed.

The average value of the coupling coordination degree of the three northeastern provinces in the past ten years is above 0.4, but the coupling degree of the northeastern region shows a decreasing trend year by year due to the growing institutional structural problems of the old industrial bases in the northeast, the weakening competitiveness of traditional pillar industries, and the influence of factors such as the transformation and upgrading of the heavy chemical value chain and the relatively slow development of university S&T innovation.

In addition to Sichuan, Chongqing, and Shaanxi, which have achieved primary coupling, the coupling coordination degree of other regions in the western region is relatively low. Due to the harsh natural environment and weak economic foundation, the average coupling and coordination degree of this region is the lowest among the four major regions of China, and there is a big gap with the eastern developed regions.

6. Discussion

On the basis of reviewing and sorting out the interaction mechanism between university S&T innovation and sustainable economic development, this paper establishes the evaluation index system from six dimensions of scientific and technological innovation input, output, environment, and the scale, structure and quality of sustainable economic development. Then, the entropy method and coupling coordination degree model are adopted. The temporal evolution and spatial pattern characteristics of coupling coordination degree in 30 provincial regions in China from 2011 to 2020 were analyzed. The following conclusions are drawn:

First, in terms of time, the coupling coordination degree between university S&T innovation and sustainable economic development in most regions of China showed a growth trend year by year, indicating that China's "innovation-driven development" strategy and sustainable economic development have achieved initial results. The coupling coordination degree of the central region is growing the fastest. However, except for the developed eastern coastal areas, the coupling coordination degree in other regions is relatively low, and the coupling coordination development should be improved. In addition, affected by the level of university S&T innovation and traditional industries, the degree of coupling coordination in some regions shows a declining trend. For example, in Northeast China, it is necessary to improve the output of university S&T innovation, the transformation of S&T achievements, industrial structure, and economic quality.

Second, in terms of space, the gap between the eastern coastal areas and the central and western regions is obvious, and the overall spatial layout is "high coupling degree in the eastern and southern China, low coupling degree in the western and northern China." Beijing and Jiangsu have reached a high level of high-quality coordination, and Shanghai, Zhejiang, Guangdong and Shandong are also in a good coordination stage. In the six central provinces, the degree of coupling coordination between Shanxi and Jiangxi is relatively low. In addition, in the western region, except for Sichuan, Chongqing and Shaanxi, other regions are on the verge of maladjustment, and Ningxia, Qinghai and other regions are even at the stage of severe maladjustment. The Bohai Rim region, the Yangtze River Delta region and the Pearl River Delta region are obviously superior to other regions, which to some extent indicates that the coordinated development of scientific and technological innovation and economy in colleges and universities needs to be further improved, which indicates the high level of coupling coordination in eastern coastal areas.

Due to the imbalance of the spatial distribution of coupling coordination degree in various regions and the limitation of economic and social development, it is urgent to narrow the gap between regions to improve the overall coupling degree. The multi-level, multi-organization, cross-regional internal and external linkage development mechanism should be constructed to consolidate the strength for the coordinated development of university S&T innovation and sustainable economic development. Firstly, it is to coordinate the university S&T innovation with economic development. For example, compared with the evaluation values of sustainable economic development, the evaluation values of university S&T innovation in Tianjin, Shanghai, and Hainan are relatively low. These provinces should focus on promoting the development of university S&T innovation to improve the coupling coordination. Instead, Jiangsu, Anhui, Hubei, and Shanxi should vigorously optimize the economic structure to promote sustainable economic development. Secondly, because industry-university research cooperation is conducive to the coordination of scientific and technological innovation and economic development [28], it is significant to encourage local governments, enterprises and institutions, as well as universities, to jointly build R&D institutions to form an innovation system with in-depth integration of industry, education and research, and give full play to the respective advantages of the three parties to achieve cross-field innovation cooperation. Thirdly, because the flow of R&D resources is conducive to stimulating the vitality of S&T innovation [29], it is meaningful to promote the rational flow of economic and scientific factors and the resources of university S&T innovation in various regions, and promote the transfer of capital, technology and talents from the eastern coastal regions to central and western regions, so as to enhance the radiating effect and driving role of coordinated regional development.

7. Conclusions

This paper constructs the evaluation index system of university S&T innovation and sustainable economic development separately. With the entropy value method, the evaluation values of university S&T innovation and sustainable economic development in 30 provincial regions in China from 2011 to 2020 are calculated. On this basis, a coupling coordination degree model is constructed to evaluate the coupling coordination degree of university S&T innovation and sustainable economic development. This study shows that the coupling coordination degree of university S&T innovation and sustainable economic development in most regions of China is increasing, but the overall coupling coordination level is low. The coupling coordination level is high in eastern and southern China and low in western and northern China. It is of great significance to improve the overall level of coupling coordination and reduce regional differences. From the perspective of time evolution and spatial pattern, this paper provides a reference for clarifying the reality of the coordination degree of university S&T innovation and sustainable economic development in China.

However, because the reasons for regional differences are very complex, this paper does not further analyze the reasons for regional disparities among China's provinces. Further research should concentrate on the related aspects of regional disparities, which may provide policymakers with a target for boosting the coupling coordination degree in low-performing provinces

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