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Spatial and Temporal Coupling Coordination and Influencing Factors of Digital Inclusive Finance and Ecological Civilization Construction in China

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Abstract. This paper uses the spatial coupled coordination model, spatial autocorrelation analysis and spatial Durbin model to explore the spatio-temporal pattern and influencing factors of the coupled coordination index between ecological civilization construction (ECC) and digital finance (DF). The results show that: (1) From 2011 to 2021, the coupling coordination degree between ECC and DF in China shows an increasing trend. Besides, the degree of coupling coordination has obvious spatial diversity. The eastern provinces are generally larger than the western provinces, and this pattern is relatively stable. (2) The coupling degree between neighboring provinces and cities has a strong positive correlation, and it is growing every year recently. (3) The test results of spatial Durbin model show that the human capital, economic growth, technological innovation and trade factors can help coupling coordination to raise. cities development and industrial structure have negative effects on coupling coordination.

Keywords: Spatial Coupling Coordination Model; ECC; DF; Influencing Factors; Spatial Econometric Model.

1. Overview

ECC is closely related to the quality of people's livelihood, and a higher ecological and environmental quality is the basis for high-quality development. Therefore, the high-quality development of ecological civilization is of great significance for China to achieve the second centenary goal. The coordinated development of economic development and ECC is inseparable from the upgrading of industries and the improvement of production efficiency. The birth and prosperity of DF benefited from the outbreak of the Internet revolution and has undergone rapid development in the past 5-10 years. The emergence of a large number of apps and small programs, such as Wechat and Alipay, has greatly improved the inclusion and availability of financial services. The advantages of DF provide new opportunities for promoting economic growth and coordinating the construction of ecological environment. Therefore, from the perspective of statistics, the relationship between digital financial inclusion and ECC is explored for the construction of green China, so as to promote China's green, low-carbon and circular development and realize the efficient use of national resources.

In terms of quantification of the degree of ECC, the relevant indicators have been established very comprehensively. Among them, Qixin (2013) constructed ecological civilization indicators based on the basic framework of "five in one" [1]. Among them, different evaluation systems had been derived for different types of regions, such as the evaluation system for ECC in ethnic minority areas developed by Yang Hongjuan et al. (2015) [2]. The above research provides a theoretical basis for this study to organize an all-sided system for measuring ECC's score in the country. In terms of the surveys about the coupling and coordinated development of ECC, there are many relevant studies in China, but they mainly target at local areas. In terms of the overall development trend, some studies believe that the inadequate and unbalanced problems of ECC and new-type urbanization development are prominent (Deng Zongbing et al., 2015) [3], Li Jianbao et al. (2019) took the Yangtze River Delta as the research object and believed that its land construction area was highly coupled with its carbon emissions [4]. In terms of the study on the influencing factors as well as the overall development trend on ECC, some studies believe that the differences of carbon emissions among regions in China

are expanding continuously, and are closely related to the industrial structure among different regions (Li Guozhi and Li Zongzhi, 2010; Li Jian and Zhou Hui, 2012) [5-6]. However, Hu Chuzhi et al. (2008) introduced the EKC curve model to the study of this field and argued that there was no inevitable relationship between China's spontaneous economic growth and carbon emissions [7]. These studies show that it is necessary to explore whether economic development and ECC are coordinated or not and the influencing factors.

In the foreign research field, there are few relevant studies using the coupled coordination model. Hu et al. (2023) measured the coupled coordination index of ECC and global tourism index in Guizhou, and believed that the two have undergone an evolution from uncoordinated to moderately coordinated during 2006-2020 [8]. In terms of regional influence, Dong et al. (2023) conducted a study using the spatial Durbin model and discovered that the points of ECC of cities in the region of Yangtze River have a significant autocorrelation [9]; Liu et al. (2020) found that the decreasing of carbon emissions among different provinces has a significant correlation [10]. However, in terms of specific influencing factors, there are no specific studies in foreign research.

At present, this paper will improve relevant research from the following perspectives. First, existing research results are based on local regions, while this paper studies the coupling and coordination law of ECC from the perspective of the whole country, so as to compare the coupling and coordination index between ECC and DF development in different provinces more intuitively from both time and space. Second, at present, there are many researches on the development of DF for high-quality and green development, but few people have studied its influencing factors while analyzing its regional and time development level. Based on the studies that relevant to coupling coordination score, this research studies its influencing factors and dynamics, and analyzes its evolution in space in China and time. Finally, different from positive and negative effects that subsystems on the construction of ecological civilization from foreign perspectives, this paper focuses on the coupling coordination index between the construction of ecological civilization and the development of inclusive DF as well as its influencing factors, which fills the research gap.

2. Research Process

2.1. Index System and Data

2.1.1. Data Source

All the data about the DF Inclusion index in research are from the Peking University Digital Financial Inclusion Index database and formed panel data from 2011 to 2020; Most of the data needed in the evaluation system of ECC comes from EPSDATA (https://www.epsnet.com.cn/). Data on the exchange rate of USD against RMB were obtained from China Statistical Yearbook (2011-2020). Data required for establishing regression model was obtained through EPSDATA. The missing data is supplemented by moving average method. Due to missing data and other special circumstances, Tibet, Hong Kong and Macao are not included in the data.

2.1.2. Index System Construction

Considering that the assessment needs to integrate the situation of different regions of the country, the evaluation system established in this study has integrated the previous literature [1-2], and finally decided to evaluate the degree of ECC in each province from four aspects: territorial space, resource environment, ecological environment and institutional improvement, taking into account the differences in policies, resources and environment in different regions. For DF, this study directly adopts the system established by the Institute of DF Inclusion from Peking University, which can quantify the development on DF in different regions.

Table 1. Assessment indicator system for ECC

	Field	Index	Efficacy
System for evaluating the level of ecological progress	Territorial space optimization	Forest coverage rate(%)	+
		The proportion of wetland area(%)	-
		Proportion of afforestation area(%)	+
		Urban population density (the number of people/ square kilometer)	-
	Resource and environment friendly	Energy consumption per unit of GDP (t standard coal/ten thousand yuan)	-
		Electricity consumption per unit of GDP(KWH/Yuan)	-
		Water consumption per unit of GDP (m^3/ 10,000 yuan)	-
		GDP/ Provincial area (Yuan/m^2)	+
	Ecological environmental protection	Industrial wastewater discharge (10000 tons)	-
		Industrial sulfur dioxide emissions (Tons)	-
		Production of industrial solid waste (10000 tons)	-
		Urban sewage treatment rate (%)	+
		Harmless disposal capacity of domestic waste (Tons/day)	+
	Level of regulation	Expenditure on energy conservation and protection accounted for the proportion of government expenditure (%)	+
		Investment in industrial pollution control (Hundred million yuan)	+

As to calculating score, we first used the min-max dimension method to standardize and isotropize each variable, and then used the entropy method to assign weights to different variables. The final score S of ecological environment construction level is:

$$S_k = \sum_{j=1}^{n} w_j Y_j \quad (1)$$

Where k represents the year, w_j represents the weight of the indicator, and Y_j represents the evaluation score of the corresponding variable in the corresponding year.

2.2. Methodology

2.2.1. Coupling Coordination Model

Coupling coordination degree model is a system that combines coupling degree and coordination degree to measure the degree of coordination and balance of elements in the system. A higher score indicates better coordination of variables within the system. In this study, we used this model to measure the coordinated development between DF development and the final score of ECC. Calculation formula of coupling coordination degree D is as follows:

$$D = \sqrt{C \times T} \quad (2)$$

In formula (2), T is the degree of coordination between the two subsystems of inclusive DF and ECC, and C is the degree of coupling between two systems.

$$C = \sqrt[k]{\frac{x_1 * x_2}{\left[\frac{x_1 + x_2}{2}\right]^2}} \tag{3}$$

$$T = x_1 k_1 + x_2 k_2 \tag{4}$$

In formula (3), C is the coupling degree of the two subsystems, and value range is [0,1], k is adjustment coefficient, here $k = 2$, k_1 and k_2 are the weights of the two variables, x_1 and x_2 are the scores of inclusive DF and ECC system respectively.

With the coupling coordination score we obtained, the coordination degree is divided as follows.

Table 2. Classification criteria and types of coupling coordination degree

D-value	Coupling type
0.1-0.3	Low coupled coordination
0.3-0.5	Moderately coupled coordination
0.5-0.7	Highly coupled coordination
0.7-0.9	Extremely coupled coordination

2.2.2. Spatial Econometric Model

(1) Spatial autocorrelation analysis

Spatial autocorrelation analysis is applied to explore the influence and correlation of a certain feature value in a certain region on the same attribute value of the adjacent unit regions. After the data cleaning, $Moran's\ I$ was used to measure the global and local autocorrelation of the coupling coordination degree between the two subsystems. Its calculation formula is shown below:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(y_i - \bar{y})(y_j - \bar{y})}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \tag{5}$$

In formula (5), n is the number of samples, S^2 represents the variance. w_{ij} is a spatial weight matrix, and a 0-1 matrix is adopted in this paper. w_{ij} is 1 when regions i and j are near each other, and 0 if they are not. The global $Moran's\ I$ value ranges from [-1,1].

(2) Spatial Durbin model (SDM)

The spatial Durbin model holds that both independent variables and dependent variables in a region are spatially correlated. Therefore, the hysteresis effects of both independent and dependent variables are included in the regression model, and the formula is as follows:

$$y = \lambda W y + X\beta + WX\delta + \varepsilon \tag{6}$$

In formula (6), $WX\delta$ represents the independent variables' influence on adjacent regions. δ represents the corresponding coefficient vector.

3. Research Results and Analysis

3.1. Spatial Evolution Characteristics and Spatial Heterogeneity of Coupling Coordination Degree

With the index system constructed above, using Stata, we can calculate the scores of the two indicators of each province in different years.

Table 3. Scores of ECC and DF in provinces and cities

Province	2011		2014		2017		2021	
	Environmental protection score	DF score	Environmental protection score	DF score	Environmental protection score	DF score	Environmental protection score	DF score
Beijing	0.5702	0.1363	0.5729	0.4997	0.6400	0.7089	0.6277	0.9571
Tianjin	0.4479	0.1115	0.4571	0.4524	0.4759	0.6311	0.4891	0.8680
Hebei	0.3986	0.0736	0.4350	0.3823	0.4751	0.5823	0.4527	0.7854
Shanxi	0.3521	0.0790	0.3439	0.3977	0.4006	0.5887	0.4217	0.7892
Inner Mongolia	0.4017	0.0577	0.4182	0.4253	0.4041	0.5938	0.3890	0.7583
Liaoning	0.4449	0.0790	0.4788	0.4392	0.4734	0.5981	0.4819	0.7914
Jilin	0.4923	0.0437	0.5057	0.3929	0.5249	0.5755	0.5395	0.7571
Heilongjiang	0.4090	0.0811	0.4380	0.4021	0.4413	0.5857	0.4701	0.7606
Shanghai	0.4507	0.1260	0.5013	0.5123	0.5491	0.7260	0.5811	0.9900
Jiangsu	0.4171	0.1016	0.4567	0.4552	0.4779	0.6553	0.4763	0.8999
Zhejiang	0.5307	0.1297	0.5634	0.4822	0.5732	0.6899	0.5784	0.9399
Anhui	0.4330	0.0642	0.4631	0.4295	0.4823	0.6128	0.4945	0.8492
Fujian	0.5658	0.1150	0.5505	0.4589	0.6034	0.6530	0.5907	0.8897
Jiangxi	0.4838	0.0598	0.4780	0.4254	0.5295	0.6055	0.5682	0.8217
Shandong	0.4333	0.0739	0.4743	0.4231	0.4840	0.6089	0.4477	0.8408
Henan	0.3566	0.0681	0.3841	0.3964	0.4275	0.6040	0.4372	0.8276
Hubei	0.4604	0.0720	0.4964	0.4386	0.5348	0.6382	0.5249	0.8592
Hunan	0.4980	0.0665	0.5140	0.3939	0.5499	0.5924	0.5156	0.8067
Guangdong	0.4808	0.1410	0.5037	0.4533	0.5419	0.6425	0.5586	0.8832
Guangxi	0.4870	0.0781	0.5211	0.3930	0.5345	0.5954	0.5493	0.7867
Hainan	0.5150	0.1030	0.5258	0.4167	0.5531	0.6096	0.5780	0.8172
Chongqing	0.5438	0.0779	0.5399	0.4295	0.5757	0.6165	0.5659	0.8209
Sichuan	0.4133	0.0800	0.4195	0.3987	0.4746	0.6063	0.4730	0.8069
Guizhou	0.3908	0.0480	0.4690	0.3850	0.5520	0.5719	0.5060	0.7550
Yunnan	0.4625	0.0535	0.4786	0.3919	0.4957	0.5817	0.5146	0.7690
Shaanxi	0.4339	0.0927	0.4605	0.4209	0.4934	0.5979	0.4982	0.8240
Gansu	0.3235	0.0587	0.3497	0.4009	0.3758	0.5512	0.3939	0.7539
Qinghai	0.3031	0.0666	0.2961	0.3497	0.3320	0.5456	0.3487	0.7400
Ningxia	0.3544	0.0620	0.3777	0.3881	0.3730	0.5714	0.3715	0.7554
Xinjiang	0.2610	0.0431	0.2565	0.3909	0.2906	0.5647	0.3041	0.7503

Through the above ECC evaluation system and digital inclusive financial index, we calculated the scores of ECC and inclusive DF index in different provinces and cities. According to standards published by the National Bureau of Statistics, China is divided into four parts, namely east, west, central and northeast. Scores of these four cities in the two subsystems showed an imbalance: "high in the east and low in the west". It shows that there is a serious development imbalance between regions.

In the score of the ECC system, Xinjiang's ECC score in 2021 was 0.3041, less than half of Beijing's. However, there is a smaller gap in the DF inclusion index scores in provinces and cities. Reasons for this situation may be that the vigorous development in Internet economy contributes to DF's prevalence across the country. The great difference in the level of ECC between different provinces and cities may be caused by the difference in the structure of natural environment and resources and the different policies implemented in different places.

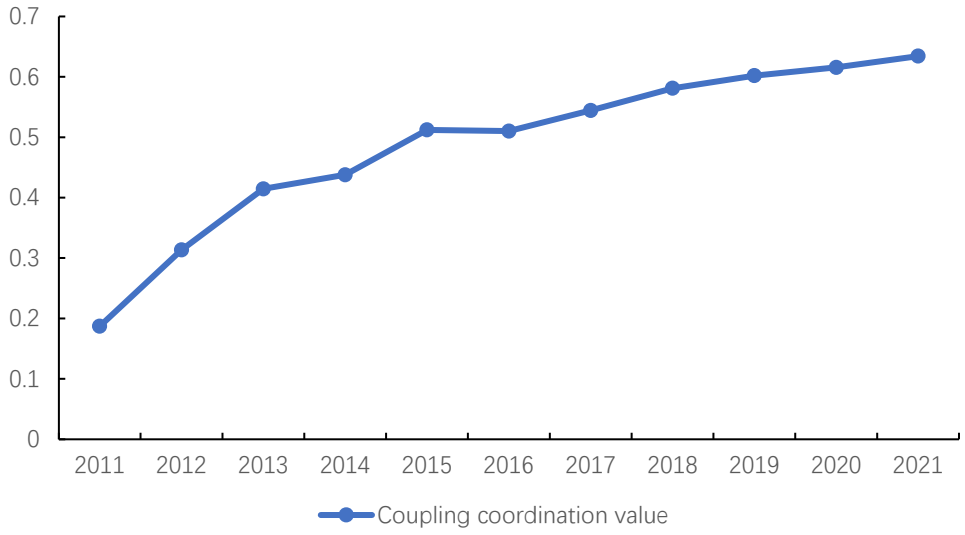

Figure 1. The coupling value and the coupling coordination value between ECC and DF

The coupling coordination degree experienced rapid development from 2011 to 2013 and maintained a high level during 2013-2021. The conclusion can be drawn from it that there is a strong coupling degree and correlation between the ECC and inclusive DF.

Combined with the calculation formula of the coupling degree and calculated score of inclusive DF and ECC, it can be drawn from the data that the growth rate of inclusive DF scores of different places is higher than that of ECC from 2011 to 2021. Between 2011 and 2021, the DF inclusion index's annual average increment was 0.7403, while the ECC's average increment was 0.0544, which can be inferred that the growth of the coupling degree from 2011 to 2013 was the result of rapid growth of inclusive DF index. The average score of the national inclusive DF index in 2021 is 0.8218, which has little room for improvement in the future. Therefore, to achieve the further coordinated development in these two subsystems in future, the government should vigorously develop ECC.

3.2. Spatial Evolution Characteristics and Spatial Heterogeneity of Coupling Coordination Degree

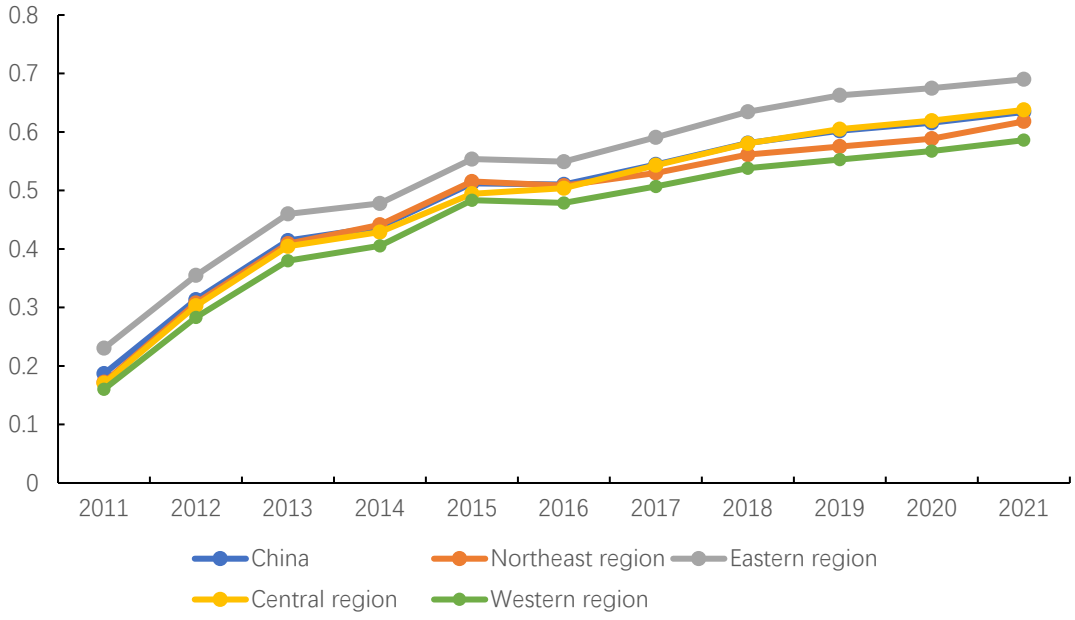

Figure 2. China's four regional coupling coordination values

The changes and development of the coupling coordination degree in different regions are shown in the figure. From a regional perspective, the coupling coordination degree between inclusive DF and ECC in these four places has increased yearly, which has proven that the development of coordination among inclusive DF and ECC. With respect to the specific value, the development of the coupling coordination degree between digital inclusive finance and ECC in the country has experienced a development from a low coupling coordination degree in 2011 to a high coupling coordination degree in 2020 and has experienced a great development leap in the middle, but still has a great development potential. From the perspective of growth rate, the coupling coordination degree grew rapidly from 2011 to 2015, but the development speed tended to be flat in 2016 and later, indicating that the coordinated development of DF and ECC has become mature after 2015. After that, more effective measures are needed to make further breakthroughs in the coordinated growth among the two. At present, coordination values in different regions of the country show an unbalanced state that the scores in eastern region are obviously higher than those in western region. Although the coupling coordination value of the whole country increased from 2011 to 2021, it further solidified this pattern during this period.

4. Influencing Factors in the Growth of Coupling and Coordination among ECC and DF

4.1. Spatial Autocorrelation Analysis

To probe the influencing factors of the coupling coordination degree between ecological civilization as well as digital financial development, this paper takes the coupling coordination degree in the two subsystems as dependent variables and conducts an autocorrelation analysis on it. We use $Moran's\ I$ to test whether it has spatial correlation, and the test results are as follows.

Table 4. National Moran Index by year

Year	I-value	Z-value	P-value
2011	0.443	3.956	0.000
2012	0.464	4.165	0.000
2013	0.452	4.066	0.000
2014	0.486	4.367	0.000
2015	0.474	4.232	0.000
2016	0.505	4.537	0.000
2017	0.517	4.611	0.000
2018	0.506	4.489	0.000
2019	0.515	4.574	0.000
2020	0.506	4.494	0.000
2021	0.540	4.774	0.000

It can be observed from the table that the $Moran's\ I$ index of each year is positive and has passed the Z-test of 1% significance level, indicating that there is an obvious spatial positive correlation between the inclusive DF index and the coupling coordination degree of ECC.

Among them, the overall $Moran's\ I$ index is on the rise, indicating that with the passage of time, digital inclusive finance and ECC will be more concentrated distribution. Then we decided to use the spatial Durbin model (SDM) to further explore the relationship among different variables.

4.2. ECC and DF

Table 5. The test results of the spatial Durbin model

Variable	Elastic coefficient	t-value	Variable	Elastic coefficient	t-value
lnstudent	0.013	0.97	W*lnstudent	0.064**	2.56
lngdp	0.107***	11.02	W*lngdp	0.007	0.37
Industry	0.002	0.49	W*Industry	-0.037***	-3.82
Rdgdp	2.197***	4.23	W*rdgdp	2.376*	2.24
TradeGDP	0.024	1.63	W*tradeGDP	0.114***	4.48
City	-0.318***	-4.38	W*city	-0.976***	-6.16

Table 6. Explain the direct and indirect effects of variables on the coupling coordination degree between ECC and DF

Variable	Direct effect	P-value	Indirect effect	P-value	Total effect	P-value
lnstudent	0.018	0.140	0.089***	0.005	0.108***	0.001
lnGDP	0.10***	0.000	0.047**	0.011	0.157***	0.000
Industry	0.0001	0.977	-0.048***	0.001	-0.048***	0.005
Rdgdp	2.369***	0.000	3.860***	0.004	6.229***	0.000
TradeGDP	0.032	0.029	0.159***	0.000	0.191***	0.000
City	-0.386***	0.000	-1.397***	0.000	-1.783***	0.000

The spatial lag term of the number of college students per 10,000 people passed the negative test with a significance of 5%, indicating that the population density of college students in surrounding area has a positive effect on the coupling coordination degree. The reason may be that college students in neighboring provinces will provide a large talent for promotion of DF and ECC, which indirectly helped local industries' expansion.

For per capita GDP (GDP), we can see that its coupling coordination degree index between inclusive DF and ECC passes the positive significance level test of 1%, indicating that the higher the local economic level development, the more conducive to promoting the coupling and coordinated development between digital financial inclusion and ECC. The reason may be that ECC and DF both need huge investment from local governments.

The spatial lag term of the ratio among the added value of the secondary industry and the added value of the tertiary industry has passed the negative significance test of 1% on the impact of inclusive DF as well as coupled coordination index of ECC, indicating that this term has a negative effect on the coupled coordination index of digital financial inclusion and ecological civilization. The reason may be that the sewage and waste gas emissions of the secondary industry are large, which could create a greater impact on the ECC of the neighboring areas.

The impact of the ratio of science and technology input to GDP (Rdgdp) and its lag term on the coupled coordination index of digital financial inclusion and ecological civilization passed the significance level test of 1% and 10% respectively, and the direction was positive, indicating that the variable had a positive effect on the development of the coupling coordination degree in local and neighboring regions. The reason may be that the investment in science directly helped in constructing DF and ECC, while the birth of new technology can also be helpful to developing of DF and ECC in neighboring regions.

The lag term of the proportion of import and export trade in GDP (TradeGDP) on the impact of inclusive DF and ECC coupling coordination index passed the positive test at the significance level of 1%. The conclusion that foreign trade revenue has a promoting effect on development of the coupling coordination of the two subsystems in neighboring provinces can be drawn from it. The reason may be that in recent years, import and export trade has adopted more green and low-carbon international standards and policies, while neighboring regions may implement similar open policies, so there is a spillover effect between neighboring provinces.

The effects of the urban population share (City) and its lagging term on the coupled coordination index of inclusive DF and ECC both pass the significance level test of 1%, and the direction is negative. It shows that the larger the proportion of urban population, the more unfavorable the coordinated development between inclusive DF and ECC. Urban life produces more pollution, and more urban population is not conducive to the construction of ECC in this province maybe the reason of this case.

5. Conclusion

This paper analyzes 30 provinces and municipalities across China, uses the spatial coupling coordination model and spatial metrology model to discover the mechanism between their ECC and DF index, and results founded in this research are shown as below.

1. The level of ECC and DF development and the degree of coupling and coordination between them show an increasing trend yearly. Moreover, there are obvious regional differences in the level of ECC and the development degree of DF. Cities and provinces in eastern China are significantly more developed than other regions. And with the progress of development, this state is constantly "solidified".

2. The coupling coordinated development index of ECC and DF development has increased year by year, but it in the phase of "high coupling and coordination" for years, and there is still room for further development in the future. At present, the four regions in China have reached the "high coupling coordination", but the development level of different regions is different. Among four regions in east, west, central and northeast, the eastern region is the first to reach the "higher coupling coordination" stage, while the western region is the latest to develop to this stage. At present, the development space of DF is small, so to further promote the coordinated development between DF and ECC, more investment is needed in ECC.

3. Coupling value between the ECC and DF’s development is affected by many factors, and different factors have different influences.

It can be divided into three aspects: economic aspect, demographic aspect and industrial aspect. In terms of economy, a large amount of investment in science and technology can be helpful in promotion of DF and ECC related technologies. At the population level, the more urban population in the province, the more urban sewage and pollutants the city needs to deal with, the more detrimental to the ECC. By the way, a big amount of college students provides a large number of talents for the promotion of DF and ECC. In terms of industry, the expansion of the secondary industry will lead to more pollution and have more detrimental to the coordinated development of ECC and DF.

Therefore, according to the results obtained from the analysis, suggestions are put forward to promote the coordinated development of ECC and DF.

(1) To deal with differences in development and similarities and differences in resources, various policies should be formulated to coordinate the coordinated development of ECC and DF considering the actual situation on the ground. For Beijing and Shanghai, which have a high degree of coupling coordination and are in a good stage of development, they should further strengthen their coupling and coordination development level, and provide capital and technology support to cities with unbalanced and inadequate development. Cities with medium or low coupling coordination degree should properly adjust their economic development mode, and actively introduce capital and new

technical talents, so as to optimize the industrial structure, break through the industrial bottleneck, and achieve the coordinated development of DF and ECC. (2) When formulating development policies in different regions, the development of neighboring regions should be considered and cooperation between regions should be strengthened. (3) Cities should take measures to improve the population structure, such as reasonably determining and regulating the urban scale, population density and urban spatial structure, optimizing the population structure, improving the population quality, and reducing the differences between different regions. At the same time, the industrial structure of different cities should be optimized and upgraded, the proportion of secondary industry should be reduced, and investment in technology-related industries should be increased.

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