

## Research Article

# Towards the Coupling Coordination Relationship between Economic Growth Quality and Environmental Regulation: An Empirical Case Study of China

Huan Huang,<sup>1</sup> Fan Wang,<sup>1</sup> Yi Xiao ,<sup>2</sup> and Jiaxin Kuang<sup>1</sup>

<sup>1</sup>College of Business, Chengdu University of Technology, Chengdu, Sichuan 610059, China

<sup>2</sup>College of Management Science, Chengdu University of Technology, Chengdu, Sichuan 610059, China

Correspondence should be addressed to Yi Xiao; [benbenyi93@163.com](mailto:benbenyi93@163.com)

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With the deterioration of the global climate, there is consensus that the environment and economy must develop in coordination. Effective environmental regulation (ER) is an important incentive of environmental protection, and there is a clear interaction mechanism between it and the economic growth quality (EGQ). In order to explore the intrinsic link between ER and EGQ, this study establishes a comprehensive evaluation index system from the research perspective of the coupling coordination degree (CCD). Based on the panel data of 30 provincial administrative regions in mainland China (excluding Tibet), from 2004 to 2017, the entropy method, coupling coordination model, and spatial econometric model are used to explore the CCD and the factors influencing the CCD of ER and EGQ. The key findings of this study were as follows: (1) The CCD of ER and EGQ system showed an upward trend in the fluctuation from 2004 to 2017. (2) In 2017, Beijing showed good coordination, Yunnan and Qinghai showed primary coordination, and the rest of the provinces showed moderate coordination. (3) The CCD of different regions in China is uneven. (4) Per capita GDP, per capita FDI, ER intensity, and industrial structure adjustment have promoting effects on the CCD, while per capita investment in fixed assets and environmental pressure have inhibiting effects on the CCD. Our conclusions are significant for promoting the integrated development of regional economy and ecological civilization, and provide a theoretical reference for other countries and regions to explore the relationship between ER and EGQ.

## 1. Introduction

As the global climate deteriorates, it is generally accepted that economic growth and environmental protection should be coordinated. Over the past four decades, China has grown at an average annual rate of about 10 percent to become the second-largest economy after the United States. But the extraordinary growth has come at the cost of environmental pollution. China paid early attention to environmental issues. Its total investment in environmental protection increased from 181.48 billion yuan in 2004 to 953.9 billion yuan in 2017, with an average annual input of 100 million US dollars (595.689 billion yuan). But environmental pressures still constrain China's economic development [1]. The Global Environmental Performance Index Report 2018 shows that China ranks 120th on the list [2].

As one of the means to promote environmental protection, ER can change the trajectory of economic growth by influencing industrial structure adjustment and technological innovation [3]. The upgrading of industrial structure is beneficial to the improvement of EGQ, which is mainly because it affects economic growth from the perspective of coordination [4, 5]. Porter Hypothesis proves that ER can promote economic growth [6–9]. However, there is a new question about whether ER will lead to unemployment, thus causing social problems and reducing the EGQ [10]. In addition, the nonlinear relationship between ER and EGQ has also been demonstrated [11–13].

It is obvious that the existing studies have not provided a consistent explanation for the impact of ER on the EGQ. Therefore, this paper embarks from the perspective of coupling coordination. The purpose is to clarify the

relationship and coupling coordination process between EGQ and ER, and to explore the key micro factors influencing economic growth and environmental regulation policies. It is of great significance to promote the integrated development of regional economic, political, social, cultural, and ecological civilizations. To achieve the above objectives, we use the CCD evaluation model and spatial econometric analysis method to explore the level of CCD and its implication factors on 30 provinces in China from 2004 to 2017. The specific work is as follows: (1) A detailed index system containing 18 specific indicators from 6 dimensions is constructed to measure the coupling coordination degree of EGQ and ER; (2) CCD model and CCD evaluation systems are built by referring to previous researches; (3) the factors affecting the CCD between ER and EGQ were discussed using the spatial econometric model; and (4) an in-depth analysis of the empirical results from the perspective of spatiotemporal evolution and spatial characteristics is made.

## 2. Literature Review

At present, there are two representative basic theories to study the economy and environment. The first is the Environmental Kuznets Curve (EKC), which proves that pollution and economy are inverted U-shaped [14]. Many scholars have explained and tested the EKC model, and proved its practicality [15]. However, with the deepening of the study on the economy and environment, there are numerous controversies about the EKC model [16–18].

Hence, a second theory: the theory deduces the response of environmental pollution to economic growth from the model [19]. It has proved three effects: scale effect, composition effect, and technology effect [20]. The scale effect is negative, while the other two effects are positive [21, 22]. In the first stage, economic growth in the early stage promotes environmental pollution under the effect of scale effect, leading to more serious environmental problems. In the second stage, economic growth produces a composition effect. The higher preference for environmental quality has led to an inherent change in policy, with policymakers attaching greater importance to cleaner production and environmental protection [23]. In the third stage, the technique effect of economic growth moves the supply curve of pollution back. Therefore, it has a significant negative impact on pollution and improves environmental quality.

As research on the relationship between the economy and the environment deepens, the international community has long been aware of the need to strengthen ER [24]. The original meaning of ER is the environmental policy effect of the government, which is a traditional tool to solve environmental problems [25, 26]. ER has the function of improving environmental quality and reducing executive cost [27]. The enforcement aspects of ER have been studied extensively [28]. More studies have examined ER from a more granular perspective. In terms of ER classification, with the development of new institutional theory, ER is gradually divided into two categories: formal ER and informal ER [29]. There are three types of ER named command-and-control

regulation, voluntary regulation, and market-based regulation [30]. In terms of ER intensity, some scholars use indicators to represent or measure the intensity of ER, such as environmental tax, sewage charge, and environmental protection investment [31–34].

In terms of the relationship between ER and economic growth, the internal relationship between ER and EGQ is complex and inconclusive. It is influenced by the combination of the combined effects of cost effects, constraint effects, and innovation compensation effects [35]. According to the cost effect, ER increases the cost of a firm's products, reduces its profits, and hinders its reproduction. Moreover, environmental economic theory suggests that firms based on optimal decisions will avoid fulfilling their environmental responsibilities. Therefore, the implementation of environmental regulations is not conducive for the improvement of environmental quality and sustainable economic growth [36]. According to the constraint effect, EGQ is constrained by the fact that firms can only arrange and organize production under a smaller decision set, which will affect the resource allocation efficiency and factor productivity of firms to a certain extent [37, 38]. According to the innovation compensation effect, ER can effectively improve the economic efficiency of enterprises by promoting their innovative behavior to force them to clean up high energy-consuming industries and promote the upgrading of industrial structure and optimal allocation of resources [1, 35, 39]. ER can also compensate for the increase in enterprise costs brought about by policies through the innovation compensation effect [40, 41]. However, some scholars have also demonstrated from industry-level data that ER does not necessarily stimulate the conduct of corporate innovation activities, or that innovation performance is not significant [42–44]. In addition, the impact of ER on innovation can be reflected not only through technological innovation, product innovation, institutional innovation, and ecological innovation but also through their interaction [45].

Coupling coordination studies have become a common method for analyzing the relationship between the environment and the economy. Originating from physics, “coupling” can measure the degree to which different systems are related [46, 47]. It can represent the degree of interconnection between modules [48]. The study of coordinated development began in the 1930s, but at that time there was too much emphasis on economic development. By the 1960s, the British economist Boulding applied the systems approach to the analysis of economic and environmental correlations [49]. Norgaard proposed the theory of coordinated development, which suggests that co-development can be achieved between society and ecosystems through feedback loops [50]. Since then, more and more scholars have been using the coupling coordination analysis method to study “environment-economy” system, and the spatiotemporal evolution trend of coordination was analyzed [51–53].

For the measurement of EGQ, some scholars use total factor productivity (TFP) to represent it [54–57]. However, with the in-depth research on green development, eco-efficiency, and sustainable development, academics generally agree that EGQ should be a concept with a richer connotation

[58–60]. Therefore, the contribution of TFP to economic development is generally declining in the fluctuation [61]. With the five development concepts of “innovation, coordination, green, opening, and sharing” proposed by the Chinese government in 2015, Chinese scholars mostly start their research on economic development from these five perspectives [66]. A typical evaluation method is to construct an index system from the structure, stability, achievement distribution, and resource utilization of economic growth. Principal component analysis (PCA), grey relational degree analysis, and entropy weight method (EWM) are the main methods to comprehensively measure EGQ level [63].

In summary, scholars have done a lot of research on ER and EGQ. Most of the research results affirm the positive role of ER in improving environmental pollution and promoting green technological innovation in enterprises. However, some scholars have also found that the effect of ER on innovation compensation is not satisfactory. In addition, a review of the literature reveals that most scholars stop at analyzing the CCD of ER and EGQ and analyze the spatial-temporal evolution characteristics, without further examining the reasons for conclusions. Therefore, the richness of the EGQ is fully considered in this paper. Based on the coupling mechanism between ER and EGQ, we establish an index system to evaluate the coordinated development level of ER and EGQ from the perspective of the CCD. The exponential change of the CCD will be analyzed from two aspects of spatiotemporal evolution and spatial characteristics. Furthermore, the main factors affecting the coordinated development are discussed by using the spatial econometric model. Through the above analysis, we hope to fully realize the coordinated development status of ER and EGQ in China, and furthermore put forward effective countermeasures and suggestions for decision-makers. The article proposes new ideas for the research field of ER and EGQ, and makes the following contributions: (1) Based on the new connotation of EGQ, this paper makes the initial effort to explore the coordinated development of ER and EGQ from the perspective of the CCD. (2) The CCD of China from 2004 to 2017 was analyzed from different perspectives of ER and EGQ, temporal and spatial, aggregate and region, respectively. (3) Furthermore, the spatial lag model is used to discuss the main factors affecting the CCD.

### 3. Methodology

**3.1. The Construction of the Indicator System.** In this paper, a comprehensive evaluation method of multiple indicators is adopted to measure ER and EGQ. The selection of indicators is based on the existing literature on the dynamically coordinated relationships of multivariate systems [64, 65].

The subsystem of EGQ includes three levels of indicators: economic growth stability, economic growth efficiency, and direct benefit of economic development. The connotation of these three dimensions is that the realization of high-quality economic growth means to realize stable economic operation and meet people’s yearning for a better life along with the improvement of economic efficiency [66]. The stability dimension of economic growth reflects the fluctuation in the

process of economic growth. Output fluctuation, employment fluctuation, and price fluctuation reflect the stability level of economic growth. Among them, output fluctuation is measured by year-on-year GDP growth rate; employment fluctuations are measured by unemployment rates; price volatility is measured by price fluctuation (year-on-year CPI growth minus target inflation). The efficiency dimension of economic growth is the core content of EGQ. Efficient economic growth essentially requires less factor input and energy consumption for the same output [67]. Therefore, the efficiency dimension of economic growth is reflected from two aspects of factor productivity and technological innovation rate. Factor productivity is measured by labor productivity (GDP/number of employees) and capital productivity (GDP/capital stock). The rate of technological innovation is measured by the proportion of technology transaction volume to GDP. The direct benefit dimension of economic growth is measured from the perspective of shared development and reflects the ability of economic growth to solve the problem of the achievement distribution. Therefore, Engel’s coefficient (the proportion of food expenditure in total expenditure) is selected to reflect poverty alleviation, while Theil Index and the labor compensation as a share of GDP are selected to reflect income distribution.

The ER subsystem includes three levels of indicators: the intensity of ER, the environmental pressure, and the performance of ER [68]. The connotation of these three dimensions is that improving the level of ER means reducing environmental pressure based on increasing the intensity of investment in ER and improving the performance of ER. The intensity dimension of ER reflects the input of factors of production to environmental protection. Human resource input and capital input are used to reflect the intensity of ER. Among them, human capital input is measured by the number of environmental protection personnel. Capital input is measured by the proportion of wastewater treatment investment (completed investment of wastewater treatment project/GDP) and the proportion of waste gas treatment investment (completed investment of waste gas treatment project/GDP). The dimension of environmental pressure reflects the environmental pollution caused by unit output. Three indicators such as wastewater discharge per unit of output, unit Sulphur dioxide emissions, and solid waste per unit of output are selected for comprehensive measurement. The environmental performance dimension is the core content of ER, which reflects the achievements of ER. The green area per capital is selected to reflect the greening construction, and household garbage harmless disposal rate and the urban sewage daily treatment capacity are selected to reflect the environmental pollution control status.

Finally, eighteen indicators are selected to represent the EGQ and ER (Table 1).

**3.2. Study Areas and Data.** Integrate the integrity of administrative units and the availability of statistical data. In the selection of interprovincial samples, there are many missing data from the Tibet Autonomous Region, while data from Hong Kong, Macao, and Taiwan are of different statistical caliber. Finally, the research area of this paper

TABLE 1: The indicator system of the CCD.

Subsystem	Criteria	Indicator	Unit	Index type	Weight	
EGQ	Stability	Year-on-year GDP growth rate	%	+	0.1190	
		Price fluctuation	—	—	0.1186	
		The unemployment rate	%	—	0.1185	
	Efficiency	Ratio of technology transaction volume to GDP	Labor productivity	Yuan/person	+	0.1094
			Capital productivity	%	+	0.1113
			Engel coefficient	%	—	0.1161
			Theil index	—	—	0.1176
	Direct benefit	Labor compensation as a share of GDP	%	+	0.1162	
	ER	Intensity	Number of environmental personnel	Person	+	0.1104
			The proportion of wastewater treatment investment	%	+	0.0998
The proportion of waste gas treatment investment			%	+	0.1026	
Pressure			Wastewater discharge per unit of output	Tons/ten thousand yuan	—	0.1180
			Unit sulphur dioxide emissions	Tons/one hundred million yuan	—	0.1183
			Solid waste per unit of output	Tons/ten thousand yuan	—	0.1184
			Green area per capital	M2/person	+	0.1136
Performance			Household garbage harmless disposal rate	%	+	0.1154
			Urban sewage daily treatment capacity	Thousands of cubic meters	+	0.1035

includes 30 provinces of China (except Tibet, Hong Kong, Macao, and Taiwan). In the selection of sample interval, this paper mainly analyzed the intrinsic link between ER and EGQ, but China's environmental policy gradually entered the deepening stage after 2000. In addition, the index data to be used in this paper such as completed investment of wastewater treatment project and the completed investment of waste gas treatment project were not counted until 2004, and the data of sulphur dioxide emissions, wastewater emissions, and solid waste production are only updated up to 2017. Therefore, the sample period selected in this paper is from 2004 to 2017. The research data are mainly from the National Bureau of Statistics of China, including the China Statistical Yearbook and China Environmental Statistical Yearbook. The missing data are made up by consulting the statistical yearbook and social statistical bulletin of each province. Based on these data, this paper studies the CCD between ER and EGQ in each province from 2004 to 2017.

### 3.3. Methods

**3.3.1. Entropy Weight Method.** The entropy weight method is an objective weighting method according to the degree of difference between different index values by constructing a judgment matrix [69]. It is based on strong mathematical theory and avoids the error caused by subjective consciousness evaluation [70].

Let  $U$  be the initial evaluation matrix,  $V_{ij}$  ( $i = 1, 2, 3, \dots, m; j = 1, 2, 3, \dots, n$ ) represents specific values.

$$U = \begin{bmatrix} V_{11} & V_{12} & \cdots & V_{1n} \\ V_{21} & V_{22} & \cdots & V_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ V_{m1} & V_{m2} & \cdots & V_{mn} \end{bmatrix}. \quad (1)$$

The original matrix is normalized by the range transformation method, as shown in formulas (2) and (3), from which the normalized matrix  $R$  can be obtained.

Positive index:

$$r_{ij} = \frac{V_{ij} - \min(V_{ij})}{\max(V_{ij}) - \min(V_{ij})}, \quad (i = 1, 2, \dots, m; j = 1, 2, \dots, n). \quad (2)$$

Negative index:

$$r_{ij} = \frac{\max(V_{ij}) - V_{ij}}{\max(V_{ij}) - \min(V_{ij})}, \quad (i = 1, 2, \dots, m; j = 1, 2, \dots, n), \quad (3)$$

where  $r_{ij}$  is the standardized value,  $\max(V_{ij})$  and  $\min(V_{ij})$  represent the maximum value and the minimum value, respectively, in the original matrix  $U$ .

Then, the information entropy ( $g$ ) of the index is obtained according to formulas (4), (5), and (6).

$$f_{ij} = \frac{r_{ij}}{\sum_{j=1}^n r_{ij}}, \quad (i = 1, 2, \dots, m; j = 1, 2, \dots, n), \quad (4)$$

$$h_j = -\frac{1}{\ln n} \sum_{i=1}^m f_{ij} \times \ln f_{ij}, \quad (j = 1, 2, \dots, n), \quad (5)$$

$$g_j = 1 - h_j. \quad (6)$$

Finally, the weight of the index ( $w$ ) is calculated according to formula (7).

$$w_j = \frac{g_j}{\sum_{j=1}^n g_j}, \quad (j = 1, 2, \dots, n). \quad (7)$$

The subsystem score is calculated according to formula (8).

$$E_i = \sum_{j=1}^{k_i} w_j \times r_{ij}, \quad (i = 1, 2), \quad (8)$$

where  $k_i$  is the number of indicators in the  $i_{th}$  subsystem,  $i = 1$  and  $2$  represent the ER subsystem and EGQ subsystem, respectively.

3.3.2. *CCD Method.* The variables VER and VEGQ represent the comprehensive evaluation index of ER subsystem and EGQ subsystem, respectively. The calculation process of the CCD is as follows:

$$C = 2\sqrt{\frac{V_{ER} \times V_{EGQ}}{(V_{ER} + V_{EGQ})^2}}, \quad (9)$$

$$T = \alpha V_{ER} + \beta V_{EGQ}, \quad (10)$$

$$CCD = \sqrt{C \times T}, \quad (11)$$

where  $C$  represents the coupling level between ER and EGQ. The higher the value of  $C$  is, the greater the correlation between EGQ and ER, and the more orderly the system is.  $T$  represents the comprehensive evaluation results of ER and EGQ, and  $\alpha$  and  $\beta$  are undetermined coefficients of ER and EGQ, with  $\alpha + \beta = 1$  and  $\alpha, \beta \in [0, 1]$ . Since the importance of ER and EGQ in the study is equal,  $\alpha = \beta = 0.5$ . The variable CCD represents the coordination between ER and EGQ, and the value range is  $[0, 1]$  from formula (10).

The CCD is divided into the following five types by summarizing the segmentation methods of ecological and economic coupling degree by many scholars (Table 2).

### 3.3.3. Spatial Lag Model

(1) *Moran's I Index.* Since there may be spatial correlation among various factors, it is necessary to conduct spatial autocorrelation test on variables before selecting an econometric model for analysis. And, the relevant statistics include Moran's I, Geary C, and Getis index [71]. In this paper, Moran's I index is as shown in formula (12) to test the global spatial autocorrelation of variables.

$$I = \frac{n \sum_{i=1}^n \sum_{j=1}^n w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{(\sum_{i=1}^n \sum_{j=1}^n w_{ij}) \sum_{i=1}^n (x_i - \bar{x})^2}, \quad (12)$$

where  $n$  is the number of provinces,  $x_i$  and  $\bar{x}$  represent the observed value and average value of region  $i$ , respectively.  $w_{ij}$  is the weight matrix of  $n$ -dimensional space. If two regions are adjacent regions, it indicates that there is a correlation between the two regions, and the weight  $w_{ij}$  is 1. If the two regions are nonadjacent regions, it indicates that there is no correlation between the two regions, and the weight  $w_{ij}$  is 0.

According to the above formula, the Moran's I index of the CCD from 2004 to 2017 is calculated, as shown in Table 3. The Moran's I index of the CCD in each year is greater than 0, with an average value of 0.276, passing the significance level test of 5%. The results show that the distribution

TABLE 2: CCD evaluation system.

C	Level	CCD	Level	$V_{ER} > V_{EGQ}$	$V_{ER} < V_{EGQ}$
[0.8, 1]	I	[0.8, 0.9]	I	EGQ hysteresis	ER hysteresis
[0.6, 0.8)	II	[0.7, 0.8)	II	EGQ hysteresis	ER hysteresis
[0.4, 0.6)	III	[0.6, 0.7)	III	EGQ hysteresis	ER hysteresis
[0.2, 0.4)	IV	[0.5, 0.6)	IV	EGQ hysteresis	ER hysteresis
[0.0, 0.2)	V	[0.4, 0.5)	V	EGQ hysteresis	ER hysteresis

Note: level I represents good coupling/coordination; level II represents moderate coupling/coordination; level III represents primary coupling/coordination; level IV represents tiny coupling/coordination; and level V represents mild coupling/coordination.

of provinces in China is not completely random, but has an obvious spatial correlation.

(2) *LM Test.* After the spatial autocorrelation test, LM statistics and robust LM statistics need to be tested to determine which model to use. Results are shown in Table 4.

Firstly, the spatial error model (SEM) and the spatial lag model (SLM) are compared through the LM test, and the model with strong significance will be selected [72, 73]. It is clear from Table 4 that the  $P$  value of LM (lag) is 0, passing the significance test of 1%. However, LM (error) does not pass the significance test. It shows that the SLM model is superior to the SEM model. In addition, considering the limited sample size of provincial panel data, the further construction of the spatial Durbin model (SDM) will lead to the waste of freedom due to too many lagged items of explanatory variables, which will affect the accuracy of regression results [74]. Therefore, the spatial quantitative analysis should be conducted, and the SLM model is more appropriate.

(3) *Hausman Test.* In panel data, the Hausman test is used to determine whether the model chooses random effects or fixed effects. Hausman test showed that at the significance level of 1%, the statistic value was 158.76, indicating that the null hypothesis was rejected and the fixed-effect model should be chosen.

(4) *SLM Model.* To sum up, the SLM model will be used to analyze the factors influencing the change of the CCD between provinces in China. The basic equation for SLM model [75] is:

$$Y_{it} = \rho \sum_{i \neq j} w_{ij} Y_{it} + \beta X_{it} + \theta \sum_{i \neq j} w_{ij} X_{it} + \mu + \varepsilon_{it}, \quad (13)$$

where  $Y_{it}$  is the explained variable (ln CCD).  $X_{it}$  is the explanatory variable.  $\rho$  is the spatial regression coefficient and reflects the spatial spillover effect,  $\beta$  is the parameters to be estimated,  $\mu$  is a vector of parameters to be estimated in the fixed-effects variant,  $\varepsilon_{it}$  represents the random error term, and  $w_{ij}$  is the spatial weight matrix based on the adjacency relationship.

The explanatory variables ( $X_{it}$ ) are treated with logarithm.  $X_{it}$  includes ln PGDP (GDP per capita) representing

TABLE 3: Global Moran' I index results.

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Moran's I	0.386	0.292	0.291	0.354	0.330	0.248	0.303	0.293	0.261	0.280	0.224	0.199	0.190	0.219
P( $\leq$ )	0.001	0.002	0.002	0.001	0.001	0.005	0.001	0.001	0.003	0.002	0.009	0.015	0.018	0.009

TABLE 4: LM test results.

Test	Statistic	df	P( $\leq$ )
Spatial error:			
Lagrange multiplier	21.659	1	0.001
Robust Lagrange multiplier	0.005	1	0.944
Spatial lag:			
Lagrange multiplier	50.072	1	0.001
Robust Lagrange multiplier	28.418	1	0.001

the stability of economic growth;  $\ln$  PFDI (per capita foreign direct investment) representing the level of scientific and technological innovation [76];  $\ln$  PFAI (per capita fixed asset investment) representing the driving effect of investment on economic growth [77];  $\ln$  NEP (number of environmental personnel) representing the intensity of ER [78];  $\ln$  PTI (the proportion of the tertiary industry) representing the adjustment of industrial structure;  $\ln$  S ( $\text{SO}_2$  emissions) representing the pressure of environmental regulations.

## 4. Results and Discussion

### 4.1. Results Analysis of Subsystems

**4.1.1. Results Analysis of the EGQ Subsystem.** By calculating the comprehensive index of the EGQ subsystem, the results of 30 provinces in China from 2004 to 2017 are shown in Table 5. The national average showed a gradual upward trend, rising from 0.449 in 2004 to 0.501 in 2017, indicating that China has shifted its emphasis from quantity to quality of economic growth. The main reasons for this phenomenon are as follows: (1) the rise in the proportion of technological transaction volume in GDP reflects the improvement of the level of scientific and technological innovation, which drives the development of EGQ; (2) the gradual rise of labor productivity reflects the continuous adjustment of industrial structure, thus improving the efficiency of economic growth; (3) the gradual decline of Engel's coefficient reflects that people have shared the dividend of economic growth, indicating that EGQ has achieved remarkable results.

The EGQ subsystem composite index ranking of 30 provinces in China in 2004, 2010, 2015, and 2017 is shown in Figure 1. The EGQ ranking of most provinces is in a state of constant fluctuation and the most volatile provinces are Shanxi and Jiangxi. Influenced by its GDP growth rate, Shanxi ranked last in 2015 and ninth in 2017, rapidly. In the past 10 years, the GDP growth rate of Shanxi Province showed a U-shaped distribution, the lowest in 2015, and gradually improved with the continuous adjustment of industrial structure. Jiangxi Province showed a trend of gradual decline, dropping from 5th place in 2004 to 24th place in 2017. This is mainly reflected in the gradually rising unemployment rate, and the brain drain problem is serious.

**4.1.2. Results Analysis of the ER Subsystem.** By calculating the comprehensive index of ER subsystem, the results of 30 provinces in China from 2004 to 2017 are shown in Table 6. The level of ER in all provinces of China shows a trend of gradual rise. The national average score rose from 0.400 in 2004 to 0.593 in 2017. Obviously, over the past 14 years, China has attached great importance to environmental issues and achieved good results in environmental quality. Due to the rapid improvement of ER, there are two provinces whose exponential growth rate exceeded 100%. Guizhou Province had the highest exponential growth rate of ER subsystem (166.13%) and Chongqing City had a growth rate of 103.07%. Qinghai Province has the lowest exponential growth rate of the ER subsystem. In 2004, the ER level of Qinghai Province was relatively high, but its growth rate was slower than that of other provinces, leading to the lowest score of ER subsystem in 2017.

The ER subsystem composite index ranking of 30 provinces in China in 2004, 2010, 2015, and 2017 is shown in Figure 2. The ranking fluctuation range of ER subsystem is obviously larger than that of the EGQ subsystem. From the perspective of space, the change of ER level is greater than the EGQ. In 2004 and 2010, Jiangsu province had the highest level of ER, while Guangdong province had the highest level of ER in 2015 and 2017.

**4.1.3. Synchronization Analysis.** Figure 3 shows the changing trend of ER subsystem index and EGQ subsystem index from 2004 to 2017. According to the rising/falling column line in the figure, it is clear that VER was less than VEGQ from 2004 to 2006, and VEGQ was less than VER from 2007 to 2017. Combined with the CCD evaluation system above, the level of ER lags from 2004 to 2006, and the level of EGQ lags from 2007 to 2017, indicating that ER has gradually played a significant role in promoting the EGQ since 2007. In 2005 and 2006, the EGQ and ER developed at the level of unified coordination most closely.

### 4.2. Results Analysis of the CCD

**4.2.1. Analysis of Temporal Changes.** As shown in Figure 4, the CCD index of China's EGQ and ER system showed an overall upward trend in the fluctuations from 2004 to 2017, with its mean value increasing from 0.6495 in 2004 to 0.7367 in 2017, an increase of 13.42% compared with 2004. It shows that the coordinated development and systematic development of China's EGQ and ER have achieved initial results. At the same time, 2009 and 2014 are the key turning points of the CCD of China's EGQ and ER system. Therefore, it can be divided into the following three stages:

2004–2008, the system coordination degree was low and increased steadily. At this stage, the CCD index of China's

TABLE 5: The comprehensive index of EGQ subsystem in 2004, 2010, 2015, and 2017.

Province	2004	2010	2015	2017	Province	2004	2010	2015	2017
Beijing	0.592	0.704	0.776	0.790	Henan	0.451	0.489	0.492	0.492
Tianjin	0.495	0.533	0.552	0.545	Hubei	0.418	0.455	0.557	0.506
Hebei	0.458	0.524	0.481	0.494	Hunan	0.441	0.483	0.469	0.460
Shanxi	0.455	0.467	0.429	0.518	Guangdong	0.558	0.556	0.554	0.552
Inner Mongolia	0.477	0.504	0.485	0.459	Guangxi	0.401	0.477	0.464	0.479
Liaoning	0.418	0.521	0.483	0.518	Hainan	0.436	0.446	0.479	0.508
Jilin	0.474	0.468	0.491	0.479	Chongqing	0.445	0.472	0.448	0.444
Heilongjiang	0.466	0.444	0.465	0.474	Sichuan	0.412	0.444	0.431	0.436
Shanghai	0.505	0.598	0.642	0.650	Guizhou	0.352	0.426	0.460	0.434
Jiangsu	0.468	0.501	0.546	0.546	Yunnan	0.293	0.358	0.431	0.437
Zhejiang	0.467	0.507	0.545	0.563	Shaanxi	0.408	0.391	0.457	0.467
Anhui	0.398	0.460	0.444	0.446	Gansu	0.437	0.423	0.458	0.440
Fujian	0.463	0.497	0.504	0.479	Qinghai	0.423	0.409	0.472	0.455
Jiangxi	0.486	0.462	0.445	0.453	NingXia	0.413	0.459	0.478	0.480
Shandong	0.467	0.488	0.486	0.494	Xinjiang	0.479	0.478	0.488	0.523

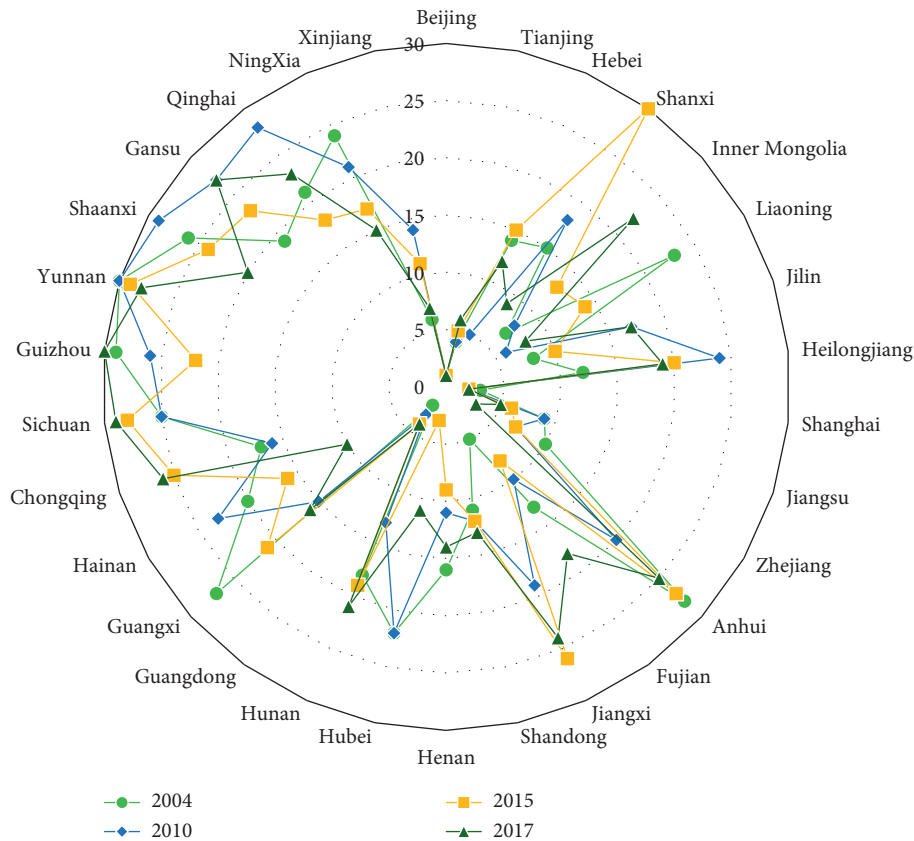


FIGURE 1: EGQ subsystem ranking in 2004, 2010, 2015, and 2017.

EGQ and ER system were in level III (primary coordination), with an average annual growth rate of 1.26% and a steady growth rate.

2009–2014, the system coordination degree fluctuated rapidly. It is worth noting that the CCD index fell significantly in 2009, down 1.99 percentage points from 2008. This is mainly due to the sharp drop in the EGQ subsystem index in 2009. Affected by the 2008 financial crisis, the overall quality of China’s economic growth is lagging. Since 2010,

the CCD index has entered level II (moderate coordination), and the trend of rapid fluctuation and the upward trend began. The average annual growth rate from 2009 to 2014 reached the highest among all stages, at 1.67%.

2015–2017 is the stage of stability and consolidation. This stage is still in level II (moderate coordination). However, the growth rate gradually slows down, with an average annual growth rate of only 0.54% from 2015 to 2017. After the upgrading of industrial structure and the establishment

TABLE 6: The comprehensive index of ER subsystem in 2004, 2010, 2015, and 2017.

Province	2004	2010	2015	2017	Province	2004	2010	2015	2017
Beijing	0.498	0.549	0.576	0.626	Henan	0.439	0.530	0.596	0.666
Tianjin	0.489	0.549	0.551	0.573	Hubei	0.400	0.493	0.552	0.574
Hebei	0.397	0.537	0.608	0.628	Hunan	0.345	0.507	0.563	0.574
Shanxi	0.359	0.532	0.574	0.616	Guangdong	0.447	0.585	0.658	0.684
Inner Mongolia	0.370	0.534	0.641	0.652	Guangxi	0.304	0.501	0.558	0.568
Liaoning	0.421	0.521	0.583	0.595	Hainan	0.421	0.493	0.564	0.566
Jilin	0.427	0.475	0.561	0.539	Chongqing	0.303	0.532	0.611	0.615
Heilongjiang	0.382	0.461	0.555	0.548	Sichuan	0.395	0.495	0.560	0.580
Shanghai	0.395	0.492	0.540	0.560	Guizhou	0.213	0.437	0.536	0.568
Jiangsu	0.519	0.609	0.653	0.668	Yunnan	0.409	0.492	0.519	0.525
Zhejiang	0.489	0.554	0.607	0.610	Shaanxi	0.351	0.539	0.573	0.584
Anhui	0.357	0.478	0.565	0.587	Gansu	0.372	0.455	0.497	0.574
Fujian	0.490	0.523	0.589	0.595	Qinghai	0.423	0.439	0.447	0.471
Jiangxi	0.364	0.508	0.549	0.564	NingXia	0.400	0.540	0.595	0.621
Shandong	0.515	0.603	0.648	0.674	Xinjiang	0.380	0.477	0.539	0.582

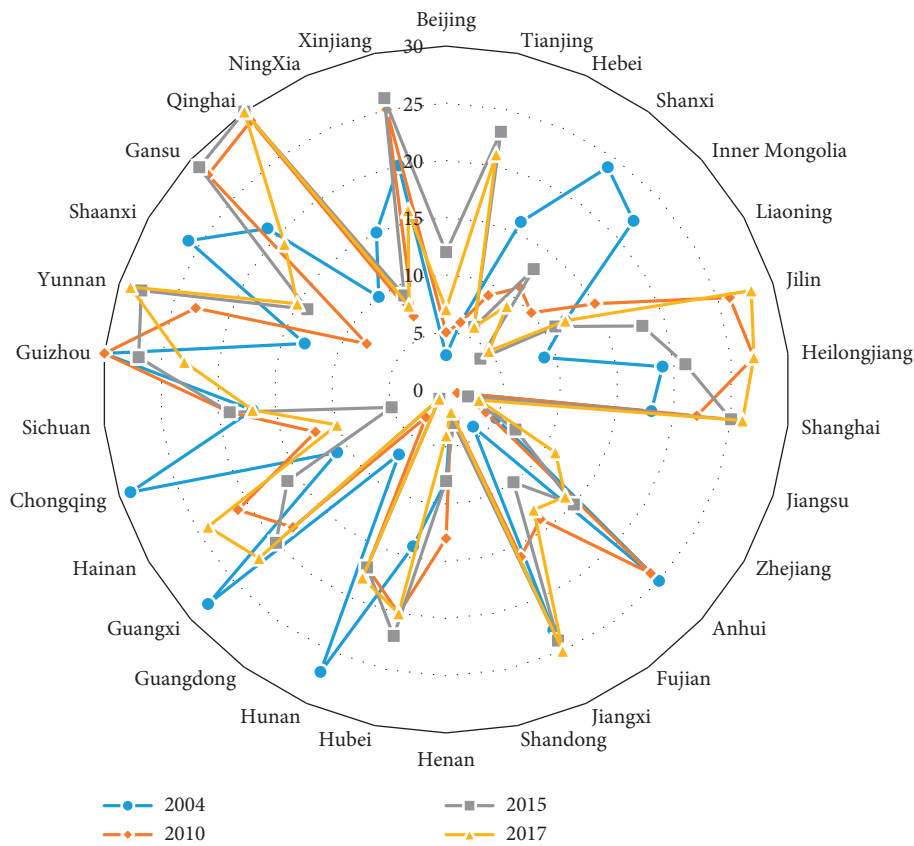


FIGURE 2: ER subsystem ranking in 2004, 2010, 2015, and 2017.

of the concept of green development in the early stage, the CCD of China’s EGQ and ER system has a relatively stable development and gradually improved.

4.2.2. *Analysis of Spatial Changes.* As shown in Figure 5, the study area is divided into eight main areas. Table 7 presents the CCD index of eight regions in China during 2004–2017. As shown in Figure 6, the longitudinal comparison of the CCD of the eight regions shows that the CCD of different

regions in China is uneven. Specifically, the CCD of the northern coast areas, the eastern coast areas, and the southern coast areas is better and has been ahead of the national average level. However, the CCD of the northeast region, the middle and lower reaches of the Yangtze River, the southwest region, and the northwest region have always lagged the national average level in the whole sample interval. The middle reaches of the Yellow River are close to the national average level. It is apparent that the coastal areas have obvious advantages in opening to the outside world in





FIGURE 3: The change trend of ER and EGQ subsystem index from 2004 to 2017.

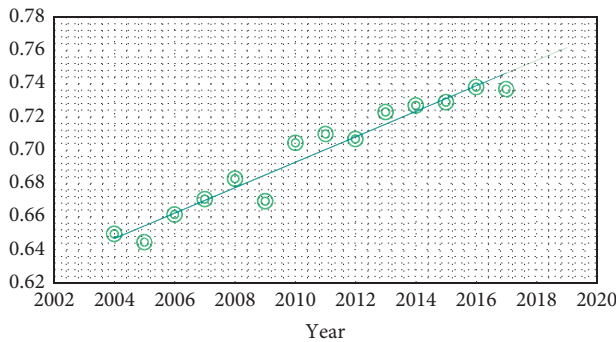


FIGURE 4: Trends of CCD average in China from 2004 to 2017.

terms of geographical location and a more mature awareness of environmental protection, making the CCD index of EGQ and ER system better than the inland areas.

Specifically, the CCD of Beijing has always been in the leading position, followed by Guangdong, and Jiangsu ranked the third during 2004–2017. In 2017, Beijing showed good coordination, which is the only province in China that is in level I. The CCD of Hebei Province in the northern coast area is slightly lower than that of other provinces, but the highest annual growth rate reaches 1.03%, indicating that the CCD of Hebei Province has a significant upward trend during the research period. Although the CCD of Shanghai and Zhejiang Province in the eastern coast area lags behind that of Jiangsu Province, it is in the forefront among the provinces in China. The variation trend of the eastern coast area is basically the same, which indicates that their CCD has a strong spatial correlation. The CCD of Guangdong Province in the southern coast area has always been at the forefront of the whole sample interval, with an average annual growth rate of 0.08%. The CCD of Anhui, Jiangxi, Hubei, and Hunan in the middle and lower reaches of the Yangtze River shows a strong convergence trend in the whole sample interval, and the average annual growth rate is relatively high, reaching 1.18%, 0.71%, 1.06%, and 1.07%, respectively. The trend of the CCD of Shanxi, Inner Mongolia, and Henan provinces in the middle reaches of the Yellow River shows strong convergence, but the CCD of

Shaanxi province is relatively low. Although it developed at a leading annual growth rate of 1.25%, the CCD is only 0.675 in 2017, ranking 24th in the country. Of the three provinces in the northeast region, only Liaoning achieved moderate coordination. The CCD of Chongqing in the southwest region is much higher than that of Yunnan and Guizhou, and the CCD of these two provinces has been lagging in the ranking of 30 provinces in China. The CCD of Xinjiang Autonomous Region in the northwest region of China is obviously better than that of Gansu, Qinghai, and Ningxia. In 2017, Yunnan and Qinghai showed primary coordination, which was the two provinces with the lowest CCD in China. Compared with the other six regions, the CCD of the eastern coast area and the middle and lower reaches of the Yangtze River shows a stronger spatial agglomeration effect.

4.3. Analysis of the Influencing Factors of CCD. The regression analysis results of the CCD index of EGQ and ER system in China using the SLM model are shown in Table 8. According to the results, the goodness of fit of the time-fixed effect model is the largest, and the parameter estimation of explanatory variables is the most significant, indicating that the SLM model under the time-fixed effect has the best fit. Therefore, this paper uses the time-fixed effect regression results for empirical analysis.

- (1) Per capita GDP is positively correlated with the CCD index. Per capita GDP represents the total economic development of a province, which reflects the improvement of the economy. It indicates that the more progressive the economic development, the more coordinated ER and EGQ are. This is in line with China’s past development philosophy of “development first, governance later”. With the expansion of the economic scale, the awareness of environmental governance has become stronger. The reason for this phenomenon may be that the increase of economic size promotes the input of regional environmental governance, thus promoting the joint development of EGQ subsystem and ER subsystem.
- (2) Per capita FDI was positively correlated with the CCD index. FDI can provide technical and financial support for enterprises [79]. The result showed that increased investment and technological progress will help raise the level of coordinated regional development. According to the “pollution halo” hypothesis confirmed by other scholars, FDI can improve enterprises’ cleaner production technologies through learning, competition, and demonstration effects [80–83]. Meanwhile, the technology spillover effect of FDI may also alleviate environmental degradation [84, 85]. Therefore, FDI can effectively promote the coordinated development of ER and EGQ.
- (3) There is a negative correlation between the per capita FAI and CCD index. Investment in fixed assets has a supply effect and demand effect on economic growth. Therefore, it can both promote economic



FIGURE 5: The subdivision of the study area into eight major regions.

development and cause fluctuations in economic growth. The result shows that the increase of per capita FAI will lead to the decline of the CCD, indicating that China is still an extensive economic growth model characterized by a large amount of capital investment during the study period, which leads to the oversupply of primary products and brings pressure to environmental protection [86].

(4) The proportion of the tertiary industry is positively correlated with the CCD index. The proportion of the tertiary industry represents the state of industrial structure. The result can be explained from two perspectives. First, the increase in the proportion of the tertiary industry inhibits the development of highly polluting industries, thus alleviating environmental pollution. On the other hand, the adjustment of industrial structure has stimulated “new drivers,” which have driven economic growth. The

TABLE 7: The CCD of China from 2004 to 2017.

Area		2004	2005	China's 11th-plan period	China's 12th-plan period	2016	2017	Mean	Growth rate (%)
North coast	Beijing	0.737	0.745	0.772	0.807	0.831	0.838	0.789	1.00
	Tianjin	0.701	0.705	0.721	0.743	0.747	0.748	0.730	0.49
	Hebei	0.653	0.664	0.693	0.732	0.742	0.746	0.709	1.03
	Shandong	0.700	0.684	0.723	0.739	0.761	0.760	0.730	0.63
East coast	Shanghai	0.668	0.663	0.713	0.750	0.784	0.777	0.729	1.16
	Jiangsu	0.702	0.706	0.728	0.760	0.782	0.777	0.743	0.79
	Zhejiang	0.691	0.682	0.711	0.745	0.765	0.766	0.728	0.79
South coast	Guangdong	0.707	0.703	0.728	0.764	0.787	0.784	0.746	0.80
	Fujian	0.690	0.687	0.692	0.727	0.734	0.730	0.710	0.44
	Hainan	0.655	0.647	0.669	0.725	0.733	0.732	0.696	0.87
Yangtze plain, middle and lower	Anhui	0.614	0.588	0.647	0.695	0.719	0.715	0.668	1.18
	Jiangxi	0.649	0.626	0.658	0.699	0.709	0.711	0.677	0.71
	Hubei	0.640	0.656	0.664	0.715	0.742	0.734	0.691	1.06
	Hunan	0.625	0.646	0.673	0.707	0.726	0.717	0.687	1.07
Middle reaches of the yellow river	Shanxi	0.636	0.642	0.685	0.711	0.721	0.752	0.695	1.30
	Inner Mongolia	0.648	0.644	0.689	0.740	0.749	0.740	0.709	1.02
	Shaanxi	0.615	0.613	0.646	0.710	0.723	0.723	0.675	1.25
	Henan	0.667	0.680	0.684	0.725	0.754	0.757	0.708	0.98
Northeast China	Liaoning	0.647	0.649	0.690	0.725	0.736	0.745	0.704	1.09
	Jilin	0.671	0.649	0.667	0.708	0.729	0.713	0.688	0.47
	Heilongjiang	0.649	0.640	0.657	0.693	0.722	0.714	0.677	0.73
Southwest China	Guangxi	0.591	0.617	0.661	0.702	0.717	0.722	0.676	1.55
	Chongqing	0.606	0.600	0.670	0.718	0.730	0.723	0.686	1.37
	Sichuan	0.635	0.625	0.658	0.689	0.710	0.709	0.673	0.85
	Guizhou	0.524	0.550	0.609	0.687	0.710	0.705	0.641	2.31
	Yunnan	0.588	0.600	0.616	0.677	0.691	0.692	0.645	1.26
Northwest China	Gansu	0.635	0.612	0.642	0.678	0.706	0.709	0.661	0.85
	Qinghai	0.651	0.616	0.641	0.664	0.692	0.680	0.655	0.34
	NingXia	0.638	0.571	0.662	0.716	0.752	0.739	0.685	1.14
	Xinjiang	0.654	0.626	0.658	0.715	0.732	0.743	0.687	0.99

Note: China's 11th-plan period represents the average score from 2006 to 2010, and China's 12th-plan period represents the average score from 2011 to 2015.

two effects promoted the synchronous increase of EGQ and ER levels, simultaneously.

- (5) The intensity of ER is positively correlated with the CCD index. According to the foregoing analysis, the score of EGQ subsystem was lower than that of ER subsystem during 2007–2017. With the improvement of ER subsystem score, the score of EGQ subsystem keeps improving. This indicates that the ER subsystem effectively promotes the increase of the EGQ level. The reason for this phenomenon may be that the increase of ER intensity controls the pollution emission of enterprises. Thus, it promoted the increase of ER level and promoted the increase of EGQ level, indirectly. In addition, ER intensity also improves the cleaner production technology of enterprises through the innovation compensation effect, which improves the level of regional coordinated development.
- (6) There is a negative correlation between environmental pressure and the CCD index. This indicates that the emission of pollutants reduces the ER level, which has a negative impact on the

coordinated development of ER and EGQ. The massive emission of pollutants is one of the typical characteristics of the past labor-intensive production mode. It shows that although the labor-intensive production mode has achieved economic benefits, it has caused great damage to the ecological environment. A development model guided by green technology innovation that considers economic benefits and environmental protection is desirable.

### 5. Conclusions and Policy Implications

5.1. *Conclusions.* In order to study the inner connection and coupling coordination process between ER and EGQ, in this paper, an evaluation index system was established, and the CCD evaluation model and spatial econometric analysis method were used to explore the level of the CCD and its influencing factors of 30 provinces in China from 2004 to 2017. The conclusions are as follows: (1) The CCD index of ER and EGQ system in the study period showed an upward trend in the fluctuation, with its mean value increasing from 0.6495 in 2004 to 0.7367 in 2017, an increase of 13.42%

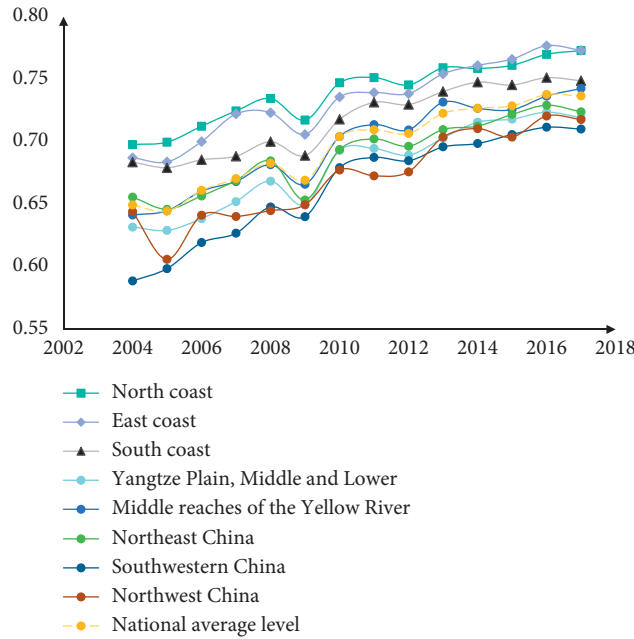


FIGURE 6: Trends of CCD in eight regions from 2004 to 2017.

TABLE 8: The regression results of the SLM model.

Variables	SLM with time fixed effects	SLM with spatial fixed effects	SLM with spatial and time fixed effects
ln PGDP	0.0544*** (14.79)	0.0218*** (6.73)	0.0176*** (5.22)
ln PFDI	0.0107*** (7.4)	0.0055*** (3.18)	0.0061*** (3.68)
ln PFAI	-0.0137*** (-4.7)	-0.0034 (-1.54)	-0.0047** (-2.09)
ln NEP	0.0036*** (2.75)	0.0088*** (3.08)	0.0147*** (5.16)
ln PTI	0.0116*** (5.39)	0.0018 (0.91)	-0.0013 (-0.67)
ln S	-0.0136*** (-4.87)	0.0001 (0.00)	-0.0053 (-1.78)
R <sup>2</sup>	0.7812	0.7456	0.6362
ρ	0.1491***	0.6092***	0.1167**
Observation	420	420	420

compared with 2004. (2) The CCD of different regions in China is obviously uneven. Specifically, the CCD of the northern coast areas, the eastern coast areas, and the southern coast areas is better and has been ahead of the national average level. The middle reaches of the Yellow River are close to the national average level. However, the CCD of the northeast region, the middle and lower reaches of the Yangtze River, the southwest region, and the northwest region have always lagged behind the national average level in the whole sample interval. The relatively backward development of the southwest region (Guangxi, Guizhou, Sichuan, Yunnan, and Chongqing) is the main reason for the low level of CCD in China. (3) Regarding the main micro factors affecting the CCD of ER and EGQ, per capita GDP, per capita FDI, ER intensity, and industrial structure adjustment must promote effects on the CCD, while per capita investment in fixed assets and ER pressure have inhibiting effects on the CCD.

The conclusions are significant for promoting the integrated development of regional economy and ecological civilization, and provide a theoretical reference for other countries and regions to explore the relationship between ER and EGQ. The research methodology of this paper is

universal and the construction of the indicator system is scientific, and researchers can draw on the methodology and indicators of this study to further explore related research in other countries or regions.

Finally, the limitation of this paper lies in the dimensionality and span of the data. On the one hand, data from Tibet, Hong Kong, Macao, and Taiwan are not considered, and on the other hand, the sample time is not new enough due to the limitation of data updates. Therefore, there are two suggestions for future research. First, scholars can refer to the method of this paper combined with the actual construction of indicator systems in other countries or regions to study the intrinsic relationship between ER and EGQ in future research. Second, scholars can further refine the research based on this paper, not only to research the influencing factors but also to study the mechanisms and paths of different types of ER on the CCD.

*5.2. Policy Implications.* Based on the above conclusions, the policy recommendations are as follows:

First is to improve the comprehensive level of the southwest region by strengthening technological innovation

and gathering talents. The conclusion suggests that the shortcomings of the CCD of ER and EGQ in China lie in the southwest. Therefore, to make up for the shortcomings, targeted policies need to be introduced to address the problems of low innovation capacity and low technological talent in southwest China. On the one hand, the Government of Southwest China should increase foreign direct investment to improve the innovation capacity of enterprises and promote the improvement of production efficiency through high technology. On the other hand, the government should actively create a new high ground for talent gathering in southwest China and improve the talent service environment to ensure attracting and retaining talent.

Second, the government should increase investment in scientific innovation and environmental pollution control. At present, China is still in the mode of extensive economic growth; the government must emphasize innovation, improve the national level of science and technology, and strengthen the supervision and control of environmental pollution. The government should strictly control heavy polluting enterprises, encourage enterprises to independently innovate technology, use the enterprise grading system, and give financial support to the leading enterprises that have achieved green technological innovation performance.

Third, the government should make efforts to adjust the industrial structure and develop strategic new industries with low energy consumption and low pollution. In the past, due to the low level of economic development, China adopted a crude economic development model with a strong reliance on resource-based industries, leading to environmental degradation and stunted economic growth. The government should promote industrial restructuring by controlling the proportion of resource-based industries and raising the access threshold for resource-based industries, and further strengthening policy support for new energy, new materials, biotechnology, and other strategic new industries. [83]

### Data Availability

Data for this article can be obtained from the corresponding author.

### Conflicts of Interest

The authors declare that they have no conflicts of interest.

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