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Analysis of Multi-Factor Dynamic Coupling and Analysis of Management Strategy Options for Urbanization in China: Evidence from the Yangtze River Economic Belt

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Abstract: The coordination of urbanization changes and their influencing factors are essential for achieving China's "balanced and sufficient" development. This study collected data on urbanization, economy, and environment from 2005 to 2019, calculated the multi-factor coordination relationship using the CD model, and analysed temporal and spatial change trends. The results show that (1) The overall coordination of the YREB has improved. (2) Downstream provinces showed better coordination than midstream and upstream provinces, and regional central provinces in the upstream and midstream regions demonstrated relative advantages within the region. (3) The study incorporated the government's environmental intervention behaviour that has been less involved in previous studies, summarizing potential government intervention strategies. The study also found that it is essential to focus on formation strategies when analysing multiple factors' coupling results rather than solely numerical values. These results can provide an analytical framework for promoting high-quality, coordinated development within regions. Furthermore, highly coupled analytical results offer insights for government governance. We did not discuss the specific mechanisms by which government policies affect urbanization development, economic development, and environmental protection, which is what we will explore with further details next.

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1. Introduction

Urbanization is perceived to be a microcosm of social processes. As China has experienced decades of GDP growth, the country has entered a phase of development positioned as a "new era". The high economic growth that has been maintained over time is not sustainable. The national development strategy has changed from the pursuit of development speed to high-quality development. However, the current situation is that urbanization development is not sufficiently coordinated across and within regions in seven dimensions. The in-coordination has produced consequences including hindering economic growth and destroying the environment. The Chinese government is working on various measures to change this situation, especially as the country begins to take on a greater international role in combating climate change, committing to a target of peaking CO2 emissions by approximately 2030 and aiming to attain it sooner. More high-quality urbanization has become a necessity. Chinese government regards solving the problem of unbalanced and inadequate development as a way to realize the people's ever-increasing needs. In this view, the coordination of urbanization, economic growth and even environmental protection is crucial for achieving a more comprehensive, balanced, and sufficient development.

2. Literature Review

2.1. Urbanization and Economic Development

After rapid urbanization since 1978, China has witnessed significant achievements in both economic and social development. The urbanization formation's basis comes from population urbanization and land urbanization. The urbanization is a process whereby the agricultural population decreases, the urban population increases, and suburban land is transformed into urban land. Rapid urbanization has produced serious negative social impacts such as the proliferation of urban population, degradation of water and soil resources, reduction of arable land area, and uncontrolled land use. The harmonization of the Chinese population urbanization and land urbanization has become an urgent issue to be addressed. Existing works have centered on the degree of coordination in population urbanization and land urbanization in provincial as well as developed regions of China (Lu, 2007), explored the interactive effects between population urbanization and land urbanization (Liu et al., 2012) and the negative effects of imbalance, as well as the impact mechanisms (Wei, 2014).

Research on urbanization has also addressed sustainable development (Jaeger, 2010), urban land use transitions (Siciliano, 2012), population migration (Zhang & Shunfeng, 2003), economics (Zhou et al., 2019), ecological environmental protection, (Wang et al., 2019) and government policies (Jin et al., 2009). At the core of sustainability of urbanization lies the coordinated development of ecological and natural environment protection, reasonable resources utilization and the fulfillment of basic human needs. Economic, social, environmental, and resource factors are incorporated into the sustainability of urbanization development. Different indicator systems and models have been developed to measure the sustainability of urbanization (Li et al., 2009; Du et al., 2006). As for urban land use change, studies mainly deal with the present situation (Pan et al., 2019), driving factors (Lin et al., 2015), economic benefits (Choi & Wang, 2017; Yu et al., 2019), and the impact on urbanization, economic development, ecology and environment (Yang et al., 2020). Substantial population migrated from rural to urban areas thanks to urbanization, resulting in large urban population growth. Many researchers have examined issues related to the historical situation of urban migration and growth (Zhang & Shunfeng, 2003), causes (Zhigang & Shunfeng, 2006), consequences of migration flows (Hu, 2002), future trends of urban migration (Cervero & Day).

There is a highly correlated link that exists between urbanization & economic development, but in some circumstances, urbanization and economic development are not fully coordinated. Studies of urbanization and economic development usually integrated the scope of natural resources, trade openness, financial development, healthcare expenditures (Ahmad et al., 2021), transport infrastructure (Maparu & Mazumder, 2017), energy consumption (Wang et al., 2018), environmental pollution (Liang & Yang, 2019), globalization (Wu et al., 2017). There is an interaction of urbanization and environmental protection. The advancement of urbanization has affected environmental quality, and simultaneously, changes in environmental quality have placed constraints on the effectiveness and sustainable and healthy development of urbanization. Specifically, urbanization has caused changes in land usage types, which have brought about serious ecological and environmental issues and threatens the harmonious relationship between human beings and the natural environment (Arneth et al., 2017; Yin et al., 2020). Geographical and ecological conditions and the environmental carrying capacity they represent act as constraints on urbanization.

The decision and implementation of government policies affects the evolution of urbanization. Researchers have focused on the role of government policies in regulating the urbanization process by investigating urbanization and government policies. Focusing on the stage of policy decision, Jim et al. used scenario analysis to model the decision framework of urbanization development. On the phase of policy implementation, Shi et al. constructed a system dynamics model to test the validity of government measures (Shi & Gill, 2015). In response to the conflicting problems of population and land due to rapid urbanization, urban containment strategies were implemented in China. Zhao et al. assessed the reliability of Chinese strategy of urban containment (Zhao, 2011).

2.2. Urbanization and Environment

In the available studies, the environmental impacts of urbanization have focused on the effects of increased urban land utilization and the effects of land utilization transitions. In exploring the influence on increased urban land utilization, Abass et al. analyzed urbanization's impact on arable land loss (Abass et al., 2018). And the results of Malek et al. showed that the increase of urban land utilization affected the crop yield, environment and water resources (Malek & Verburg, 2020). In terms of analyzing the impact of regional land utilization transition on the environment, Asabere et al. (2020) and Yang et al. (2020) have carried out ample theoretical, methodological and empirical investigations. Changes in system service values or environmental quality indices have received increasing attention from scholars in these studies. Xu et al. discovered through an econometric analysis of cropland utilization variation that 8.2 million hectares of cropland were replaced by construction land in the 12-year period of rapid development in China from 1997 to 2009. (Xu et al., 2013) The massive loss of arable land area can be attributed to a combination of policy factors, regional economy and geographical environment factors.

Researchers have discussed environmental constraints and influences on urbanization, mainly focusing on the influence of geography on land use type changes. Godschalk (1975) argued that factors in the environment that influence land planning and urbanization construction are also local physical conditions and environmental carrying capacity. Zhao & Chen (2018) argued that due to the significant differences brought by hydrothermal conditions, geography has an impact on green space changes.

When discussing urbanization-environment coordination, researchers generally adopted dynamic coupling coordination degree models to estimate the relations. Zhao et al. (2017) investigated the global urbanization-environment coupling relationship by examining the World Bank data of 209 countries and regions worldwide. Wang et al. (2014) used the urbanization and environment data of Beijing-Tianjin-Hebei region to study the relationship.

2.3. Economic Development and Environment

In recent years, research on economic development-environment relationship can be broadly classified into the following 3 dimensions.

Looking at the impact of economic development on the environment, previous works have revealed that socio-economic factors were fundamental in the urbanization changes, mainly in the environmental damage caused by the increasing area of urban construction land. However, scholars have also found that economic development has contributed to environmental improvement regarding the change in urban green area. Richards et al. (2017) concluded through their study that GDP showed a positive relationship with the increase in urban green area. Wilkerson et al. (2018) concluded that as a result of socioeconomic development, residents' demand for services represented by green space increased after they met their basic needs, and eventually the government chose to invest more resources in urban green space in public policy.

In the discussion of environmental influence on economic development, research has focused on the environmental carrying capacity. Environmental carrying capacity is being defined as the competence of an area's environmental resources to sustain the maximum of human activities within a certain time period. It is an overwhelming reference and powerful tool for economic policy formulation and management in the process of economic development. (Liu et al., 2011) Specht's (1993) research on the environmental carrying capacity of forest resources shows that both resource scarcity and environmental pollution can affect regional economic development. Through a comprehensive analysis of the water resources' carrying capacity in China, Yang et al. (2015) concluded that water resource crisis can limit regional economic growth.

From the aspect of the economic development- environment coordination relationship, scholars have conducted studies on the coordination relationship between resources (Bass et al., 2010), environment (Saveriades, 2000), economic development (Li & Yi, 2020), land urbanization (Ariken et al., 2020), and population urbanization (Liu et al., 2012). Such studies mainly use coupling coordination models to seize the coordination relationships among variables, and the scope of application covers mainly urban (Li & Yi, 2020; Fan et al., 2019) and urban agglomerations (Wang et al., 2014; Wu et al., 2020), followed by regions (Li et al., 2022), and finally national (Liu et al., 2018) and world scale (Zhao et al., 2017). On the basis, scholars have undertaken research on how to promote regional economic sustainability based on regional resource and environmental conditions (Santoso et al., 2014). It has also given rise to a focus on public policy decisions of local governments that choose between conservation and development. However, these studies have set sights on models of the economic development-environment coordination relationship, while comprehensive studies that examine the role of government public policy and decision-making mechanisms in urbanization as an object of study are lacking. Therefore, we will add government environmental policies to the analysis, explore the coordination between urbanization, economic growth and environmental protection, and then discuss potential government intervention strategies to contribute new ideas to the study of coordinated regional development.

3. Materials and methods

3.1. Study Area

The study area is presented in Figure 1. The YREB is located along the Yangtze River in China, covering 11 provinces and cities, including Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Yunnan and Guizhou, with an estimated area of 2,052,300 square kilometers, occupying 21.4% of the entire country. The YREB has a vast water area and a large range of economic hinterland, as well as rich resource advantages and a solid foundation in agriculture, transportation, information, science and technology, with great development potential. The development of YREB is one of the "Three Strategies" implemented by the Chinese government. In September 2016, the Outline of the YREB Development Plan was issued, establishing a new development paradigm for YREB (Chen et al., 2017). The policy direction lies in promoting economic development while vigorously protecting the Yangtze River's ecological environment. The YREB straddles three major regions in eastern and western China, combining two developed inland regions, the Chengdu-Chongqing area and the Wuhan area, with the coastal economic belt with Zhejiang, Jiangsu and Shanghai as its core. As of 2019, the regional GDP of the YREB rose to 4,578.5 billion yuan, up 6.9% from last year, of which the Yangtze River Delta's regional GDP was 2,725.3 billion yuan, up 6.4%. The YREB is one of the most economically dynamic regions in China, but also a region where the economic development and ecological environment are in conflict.

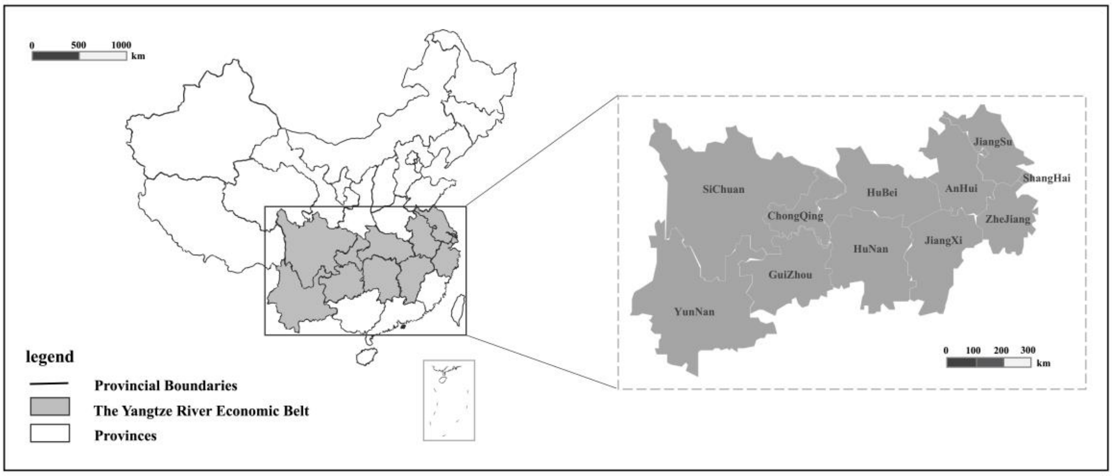

Figure 1. Location of the YREB in China.

3.2. Methods

The study aims to discuss the economic development-environmental protection-government policy coordination relationship that may affect the development of urbanization, so we adopt the coupling degree (CD)model. Before we properly applying the coupling degree model, we need to develop a index system to assess the level of urbanization, economic development, environmental protection, and government strategies to ensure that research can be conducted based on available objective data.

By reviewing the existing classic evaluation indicators (Chen et al., 2017; Li et al., 2021), under the premise of the availability and accuracy of the data, we have selected the most refined ones that can be employed to measure the development of urbanization (UD), economic development (ED), environmental protection (EP), and the government policy (GP). In the final indicator system, there are four indicators in the two dimensions of population urbanization and land urbanization to evaluate the urbanization level, and four indicators in the two dimensions of economic growth and fiscal growth to evaluate the economic development level, and five indicators to assess the level of environmental protection under the three dimensions of greenery, water resources and pollutant emissions. The number and proportion of environmental protection policies under the government's intervention dimension are used to measure the government's role in balancing various development processes. We referenced 30 statistical yearbooks containing data in the YREB from 2005 to 2019, and collected and processed policy data from 11 provincial government websites. The specific indexes we used can be found in Table 1.

The evaluation indicators differ in dimensionality and magnitude depending on the nature of the evaluation indicators. The indicators cannot be directly compared when the dimensions are different. The utility of larger numerical indicators is highlighted when the numerical values of the indicator data vary widely, which will weaken the effect of smaller numerical indicators, so normalization of the raw index data is necessary to ensure the accuracy and reliability of evaluation results. The study uses min-max scaling to uniformly map the evaluation data to the [0,1] interval, and the method is as follows:

$$a'_{ijk} \begin{cases} \dfrac{a_{ijk} - min\{a_{1jk}, a_{2jk}, \dots, a_{mjk}\}}{max\{a_{1jk}, a_{2jk}, \dots, a_{mjk}\} - min\{a_{1jk}, a_{2jk}, \dots, a_{mjk}\}} & \text{Positive Indicator} \\ \dfrac{max\{a_{1jk}, a_{2jk}, \dots, a_{mjk}\} - a_{ijk}}{max\{a_{1jk}, a_{2jk}, \dots, a_{mjk}\} - min\{a_{1jk}, a_{2jk}, \dots, a_{mjk}\}} & \text{Negative Indicator} \end{cases} \quad (1)$$

Where $a'_{ij\,k}$ is the standardized value, $a_{ij\,k}$ represents the value of the index j of the kth province in year i, $\min\{a_{1jk}, a_{2jk}, \dots, a_{mj}k\}$ and $\max\{a_{1jk}, a_{2jk}, \dots, a_{mjk}\}$ respectively stand for the minimum and maximum values of the index j for all provinces and all years.

For identifying index weights as scientifically as possible and avoiding potential mistakes of using purely objective or subjective approaches to calculate index weights, the paper chooses a combination of entropy method (EM) and hierarchical analysis (AHP) to determine weights by incorporating subjective and objective analysis.

The AHP was first adopted, with 4 authors and 5 experts constructing an analysis matrix and calculating the weights of each indicator w_1. The entropy value method is then applied to ascertain the weights of each index. The specific principles are:

First of all, since the minimum value after standardization will appear as a zero and the zero cannot participate in the entropy calculation. It is necessary to perform translation processing on the normalization results of various data and then standardize the indicators.

$$Z_{ijk} = a'_{ijk} + 1 \quad (2)$$

Secondly, the standardized indicators need to be normalized again.

$$P_{ijk} = \frac{Z_{ijk}}{\sum_{i=1}^{m}\sum_{k=1}^{n} Z_{ijk}} \quad (3)$$

Third, calculate the entropy value of each indicator for the normalized data.

$$E_j = -x \sum_{i=1}^{m} \sum_{k=1}^{n} P_{ijk} ln P_{ijk} \ and\ x = \frac{1}{\ln(i \times k)} \quad (4)$$

Fourth, through the results of entropy calculations, the redundancy of various indicators is further calculated.

$$D_J = 1 - E_j \quad (5)$$

Finally, calculate the weights of various indicators.

$$W_j = \frac{D_j}{\sum_{j=1}^{u} D_j} \quad (6)$$

For the weights derived by the AHP and EM, the subjective weight w_{1i} and the objective weight w_{2i} of the comprehensive indicator can be combined to get the combined weight w_i, $i = 1 \sim m$. w_i should be the closest possible to w_{1i} and w_{2i}. Based on the principle of minimum relative information entropy, we adopted the Lagrange multiplier method to generate an optimal combination weight calculation formula. The results of the weight calculation are shown in Table 1.

$$w_i = \frac{(w_{1i} w_{2i})^{\frac{1}{2}}}{\sum_{i=1}^{m} (w_{1i}, w_{2i})^{\frac{1}{2}}} (i = 1,2,3, \cdots, m) \quad (7)$$

After obtaining the final weights, the weights can be used to calculate the evaluation results of the urbanization development (UD), economic development (ED), environmental protection（EP）, and government policy (GP) in each statistical period.

$$UD = \sum_{j=1}^{n} w_{UD} V_j \quad (8)$$

$$ED = \sum_{j=1}^{n} w_{ED} X_j \quad (9)$$

$$EP = \sum_{j=1}^{n} w_{EP} Y_j \quad (10)$$

$$GP = \sum_{j=1}^{n} w_{GP} Z_j \quad (11)$$

Table 1. Evaluation indicator system for coupling degree of UD, ED, EP and GP.

Target Layer	Domain level	Criterion Layer	Index layer	AHP	EM	Weight
Multiple Factors of Urbanization Change in China	UD	Population urbanization	Urban Population	0.2104	0.2807	0.2489
			Proportion of Urban Population	0.2241	0.2783	0.2557
		Land urbanization	Area of Land Used for Urban Construction	0.2693	0.2919	0.2814
			Land Used for Urban Construction as Percentage to Urban Area	0.2962	0.1491	0.2140
	ED	Economic	Gross Domestic Product (GDP)	0.2313	0.2029	0.2169
			Per Capita GDP	0.2641	0.2357	0.2498

	Development	Gross Regional Product Index (Previous year = 100)	0.2836	0.2691	0.2788
	Financial growth	General Budgetary Local Government Revenue	0.221	0.2923	0.2545
EP	Greenery	Green Coverage	0.3014	0.2618	0.2851
	Water Resources	Per Capita Water Resource	0.2871	0.2945	0.2902
	Pollutant Emissions	Total Emissions of Carbon Dioxide	0.1247	0.1188	0.1203
		Total Emissions of Waste Water	0.1332	0.2107	0.1700
		Volume of Industrial Solid Wastes Discharged	0.1536	0.1141	0.1344
GP	Administrative intervention	Number of Regional Environmental Policies	0.4854	0.5088	0.4972
		Regional Environmental Policies as Percentage to Regional Total Policies	0.5146	0.4912	0.5028

Among them, UD, ED, EP and GP are the measured urbanization development level, economic development level, environmental protection level, and government policy intervention level within the prescribed years. V_jX_j, Y_j and Z_j are respectively normalized values based on various index data, and w_{UD}, w_{ED}, w_{Ep}, and w_{GP} stand for the corresponding weights. On the basis of the conceptual analysis of coupling, the smaller the difference among UD, ED, EP, and GP, the higher the degree of coupling. Therefore, we introduce the CD model to measure the level of coordination between factors:

$$CD = \left\{ \frac{\prod_{i=1}^{n} INDEX}{\left[\frac{\sum_{i=1}^{n} INDEX}{n}\right]^{n}} \right\}^{n} \tag{12}$$

According to the CD model, when measuring the coupling degree between UD level and ED level or any other two, n=2. When measuring the coupling degree among the UD level, ED level and EP level, n=3.When comprehensively measuring the level of UD, ED, EP, and GP, n=4, and INDEX is the value of the measured index respectively.

To easily understand the coupling degree model calculation results, and intuitively realize the coupling degree shown by different provinces in different indicators, we divide the coupling degree into four levels: when the CD value is lower than 0.3, the result is Severe Imbalance(SI); When the CD value is between 0.3 and 0.5, the result is Low Coordination(LC); when the CD value is between 0.5 and 0.8, the result is Medium Coordination(MC); when the CD value is greater than 0.8, the result is High Coordination (HC) (Liao et al., 2012). We calculated a total of 5 coupling degrees in three categories. See Table 2 for the specific classification criteria.

Table 2. Classification criteria for coupling degree.

Coupling degree	$0.8 \leq CD \leq 1$	$0.5 \leq CD < 0.8$	$0.3 \leq CD < 0.5$	$0 \leq CD < 0.3$
Coordination level	High Coordination (HC)	Medium Coordination (MC)	Low Coordination (LC)	Severe Imbalance (SI)

Specific Type	CD2(UD-ED)	If UD >ED, ED lag	UD-ED
		If ED>UD, UD lag	ED-UD
	CD2(ED-EP)	If UD >EP, EP lag	UD-EP
		If EP>UD, UD lag	EP-UD
	CD2(ED-EP)	If ED >EP, EP lag	ED-EP
		If EP>ED, ED lag	EP-ED
	CD3 (UD-ED- EP)	If UD >ED>EP, EP lag	UD-ED-EP
		If UD >EP>ED, ED lag	UD-EP-ED
		If ED >UD>EP, EP lag	ED-UD-EP
		If ED >EP>UD, UD lag	ED-EP-UD
		If EP >UD>ED, ED lag	EP-UD-ED
		If EP >ED>UD, UD lag	EP-ED-UD

Each Specific Type can be combined with the coupling degree. For example, when UD> ED and the coupling degree between UD and ED is between 0.8 to 1, it is recorded as H-UD-ED.

4. Results

4.1. Coupling Degree of UD&ED, UD& EP, ED&EP

Through the calculation of the coupling degree model (CD), three coupling evaluation results of urbanization (UD)and economic development (ED), urbanization and environmental protection (EP), and ED and EP are derived in the paper, respectively. In this paper, the CD values of 11 provinces in the YREB were calculated in the 3 stages of 2005-2009, 2010-2014 and 2015-2019. See the results in Table 3.

Table 3 shows that the CD values of all provinces except Shanghai, Yunnan, and Guizhou are higher than 0.9, reflecting a high coordination level. However, Shanghai, Yunnan, and Guizhou have lower CD values at some stages, Guizhou has the lowest CD values from 2010-2014 at 0.51. It can be seen that the provinces with average CD values are listed from highest to lowest as Zhejiang, Hubei, Jiangxi, Jiangsu, Hunan, Chongqing, Anhui, Sichuan, Yunnan, Shanghai, and Guizhou.

Table 3. Coupling degree of UD&ED, UD& EP, ED&EP, UD&ED& EP.

Provinces		Sichuan	Guizhou	Yunnan	Chongqing	Hubei
2005-2009	ED	0.23	0.17	0.15	0.23	0.23
	EP	0.52	0.51	0.62	0.42	0.46
	UD	0.24	0.07	0.1	0.18	0.23
	CD2(ED-EP)	0.71	0.57	0.4	0.84	0.78
	CD2(UD-ED)	0.99	0.68	0.92	0.97	0.99
	CD2(UD-EP)	0.76	0.18	0.23	0.7	0.79
	CD3	0.51	0.06	0.06	0.55	0.59
	Specific Type	M-EP-UD-ED	S-EP-ED-UD	S-EP-ED-UD	M-EP-ED-UD	M-EP-UD-ED
2010-2014	ED	0.3	0.23	0.22	0.31	0.29
	EP	0.57	0.55	0.58	0.5	0.46
	UD	0.32	0.07	0.13	0.22	0.34
	CD2(ED-EP)	0.81	0.68	0.65	0.9	0.91
	CD2(UD-ED)	0.99	0.51	0.88	0.94	0.99
	CD2(UD-EP)	0.85	0.15	0.38	0.71	0.96
	CD3	0.67	0.06	0.19	0.59	0.85
	Specific Type	M-EP-UD-ED	S-EP-ED-UD	S-EP-ED-UD	M-EP-ED-UD	H-EP-UD-ED
2015-2019	ED	0.29	0.21	0.21	0.26	0.31
	EP	0.57	0.59	0.64	0.51	0.5
	UD	0.45	0.14	0.2	0.29	0.39
	CD2(ED-EP)	0.8	0.61	0.55	0.8	0.89
	CD2(UD-ED)	0.91	0.91	0.99	0.99	0.97
	CD2(UD-EP)	0.97	0.38	0.52	0.85	0.97
	CD3	0.71	0.18	0.24	0.66	0.84
	Specific Type	M-EP-UD-ED	S-EP-ED-UD	S-EP-ED-UD	M-EP-UD-ED	H-EP-UD-ED
Average CD2(ED-EP)		0.77	0.62	0.53	0.85	0.86
Average CD2(UD-ED)		0.96	0.7	0.93	0.97	0.98
Average CD2(UD-EP)		0.86	0.24	0.38	0.75	0.91
Average CD3		0.63	0.1	0.16	0.6	0.76

CD3 indicates the coupling degree of UD&ED&EP.

Continued Table 3. Coupling degree of UD&ED, UD& EP, ED&EP, UD&ED& EP.

Provinces		Hunan	Jiangxi	Anhui	Shanghai	Jiangsu	Zhejiang
2005-2009	ED	0.23	0.2	0.2	0.3	0.34	0.27
	EP	0.49	0.59	0.49	0.41	0.42	0.46
	UD	0.24	0.16	0.24	0.61	0.44	0.34
	CD2(ED-EP)	0.75	0.57	0.68	0.96	0.98	0.88
	CD2(UD-ED)	0.99	0.98	0.98	0.79	0.97	0.98
	CD2(UD-EP)	0.78	0.45	0.79	0.92	0.99	0.95
	CD3	0.56	0.21	0.5	0.69	0.95	0.81
	Specific Type	M-EP-UD-ED	L-EP-ED-UD	M-EP-UD-ED	M-UD-EP-ED	H-UD-EP-ED	H-EP-UD-ED
2010-2014	ED	0.27	0.23	0.26	0.35	0.48	0.33
	EP	0.51	0.62	0.47	0.47	0.43	0.49
	UD	0.3	0.22	0.3	0.55	0.58	0.39
	CD2(ED-EP)	0.82	0.62	0.84	0.95	0.99	0.93
	CD2(UD-ED)	0.99	0.99	0.99	0.9	0.98	0.99
	CD2(UD-EP)	0.87	0.59	0.9	0.99	0.96	0.98
	CD3	0.7	0.32	0.74	0.85	0.94	0.89
	Specific Type	M-EP-UD-ED	L-EP-ED-UD	M-EP-UD-ED	H-UD-EP-ED	H-UD-ED-EP	H-EP-UD-ED
2015-2019	ED	0.27	0.23	0.26	0.49	0.61	0.46
	EP	0.53	0.63	0.51	0.5	0.47	0.51
	UD	0.37	0.29	0.39	0.48	0.68	0.45
	CD2(ED-EP)	0.79	0.62	0.81	0.99	0.96	0.99
	CD2(UD-ED)	0.94	0.98	0.93	0.99	0.99	0.99
	CD2(UD-EP)	0.94	0.74	0.97	0.99	0.94	0.99
	CD3	0.7	0.42	0.73	0.99	0.9	0.98
	Specific Type	M-EP-UD-ED	L-EP-UD-ED	M-EP-UD-ED	H-EP-ED-UD	H-UD-ED-EP	H-EP-ED-UD
Average CD2(ED-EP)		0.79	0.6	0.78	0.97	0.98	0.93
Average CD2(UD-ED)		0.97	0.98	0.97	0.89	0.98	0.99
Average CD2(UD-EP)		0.86	0.59	0.89	0.97	0.96	0.97

Average CD3	0.65	0.32	0.66	0.84	0.93	0.89

CD3 indicates the coupling degree of UD&ED&EP.

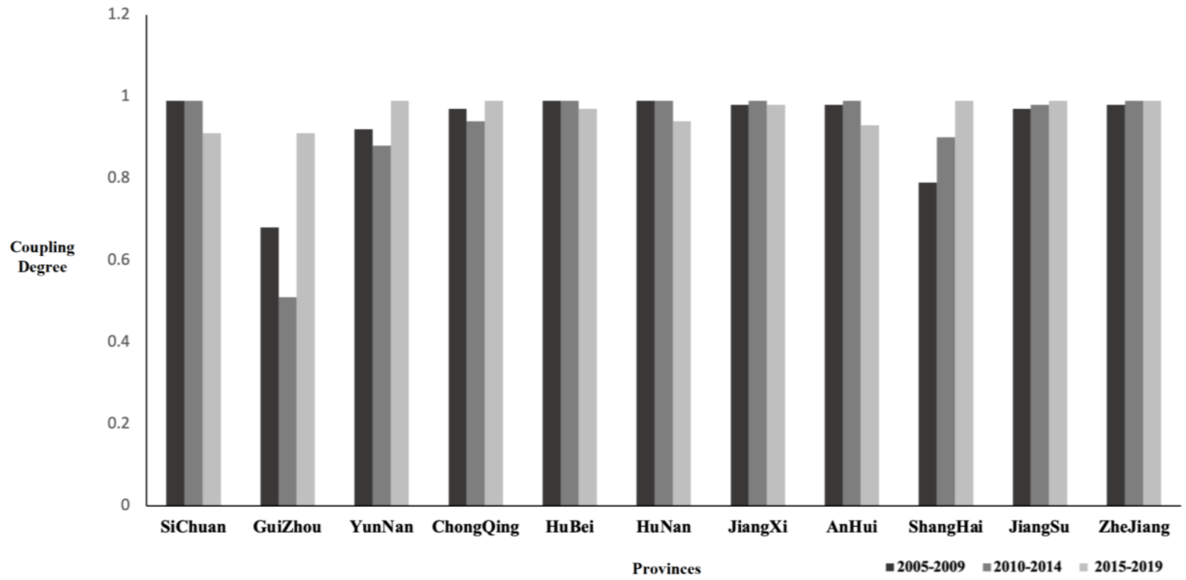

Figure 2. Changes of the coupling degree of UD and ED of YREB.

While Shanghai, Yunnan, and Guizhou have lower CD values at some stages. Guizhou has the lowest CD values from 2010-2014 at 0.51. It can be observed that the ranking of the average CD value is from high to low as Zhejiang, Hubei, Jiangxi, Jiangsu, Hunan, Chongqing, Anhui, Sichuan, Yunnan, Shanghai, and Guizhou. Regarding the trend of the coupling degree, Shanghai, Jiangsu, and Zhejiang showed increasing trends, while Sichuan, Hubei, Hunan, and Anhui showed decreasing trends (Figure 2).

The spatial distribution of UD and ED in the YREB (Figure 5) shows that the provinces with CD values greater than 0.8 is increasing. Complete coverage was reached from 2010-2014, showing a high coordination level. Guizhou in the western part of the YREB shows a lagging trend with a CD value of 0.68 in 2005-2009, which is far behind the average, and only achieved a high CD value of 0.91 in 2014-2019.

Data on the coupling degree of UD and EP (Table 3) shows that Zhejiang, Shanghai, and Jiangsu all possess CD values higher than 0.9, reflecting a high coordination level; Hubei suffers from a low CD value in the phase 2005-2009, followed by an upward trend, with CD values higher than 0.9 in 2010-2014 and 2014-2019. while Jiangxi, Yunnan, and Guizhou present low CD values, showing lower coordination degree. Among them, Jiangxi shows an increasing trend, rising from a low CD value of 0.45 in the phase of 2005-2009 to a medium coordination level of 0.74 in the CD value of 2014-2019. While Guizhou has a low CD value of 0.15 in 2010-2014. In general, the ranking of the average CD values from high to low are Zhejiang, Shanghai, Jiangsu, Hubei, Anhui, Hunan, Sichuan, Chongqing, Jiangxi, Yunnan, and Guizhou. All provinces except Jiangsu showed increasing trends (Figure 3).

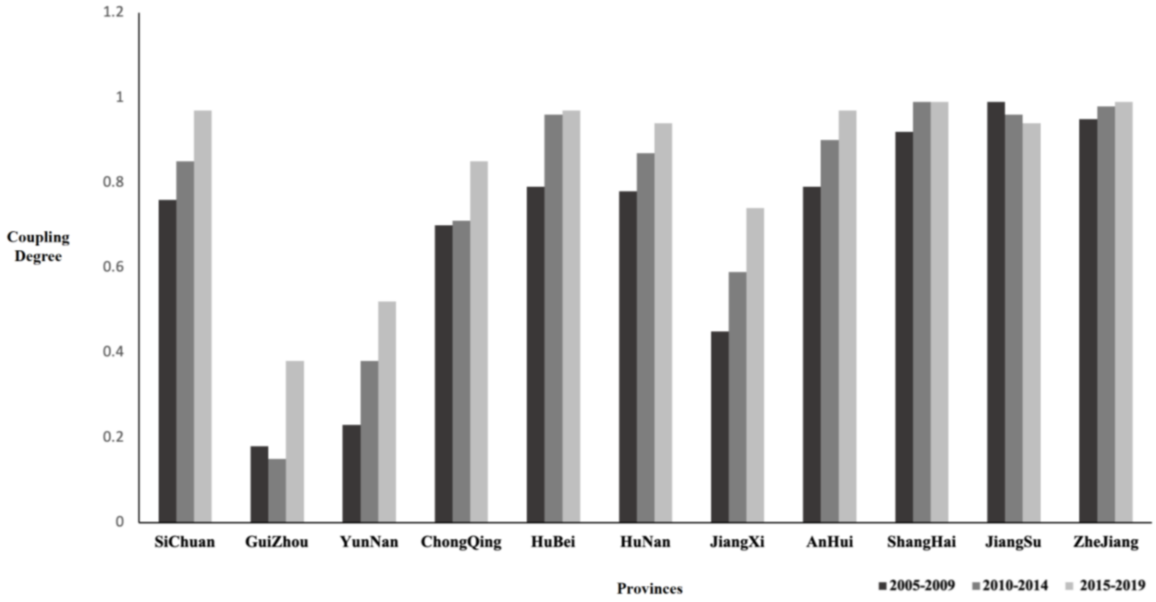

Figure 3. Changes of the coupling degree of UD & EP of YREB.

The coupling degree spatial distribution of UD & EP (Figure 5) shows that, overall, the CD values of UD and EP from 2005 to 2009 are generally at a medium coordination level, and there are great differences between the two poles. Among them, Zhejiang, Shanghai, and Jiangsu in the eastern part of the YREB are at a high level of coordination. While Yunnan and Guizhou in the west have CD values less than 0.3, which belong to severe imbalance coordination level. 2010-2014, provinces with CD values greater than 0.8 is increasing. By 2014-2019, the CD values of UD and ED in the YREB exceed 0.8, except for Jiangxi, Yunnan, and Guizhou, which reach a high coordination level.

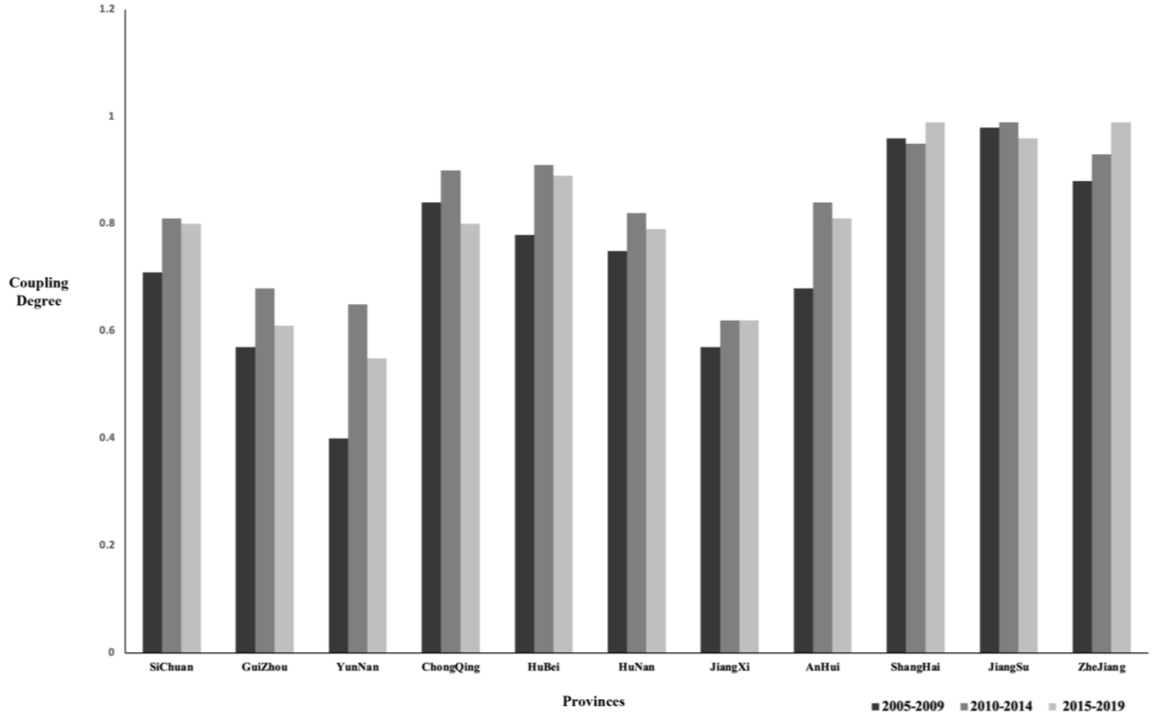

Figure 4. Changes of the coupling degree of ED & EP of the YREB.

The ED & EP coupling degree data (Table 3) shows that Shanghai and Jiangsu both have CD values above 0.9, and Zhejiang also exceeds 0.9 except for the CD value of 0.88 from 2005 to 2009, reflecting a relatively stable high coordination level. Hubei and Chongqing follow closely behind with mean CD values above 0.8, representing a high coordination level. Guizhou, Jiangxi, and Yunnan, on the other hand, have lower CD values, with Yunnan showing a low coordination level with a CD value of 0.4 from 2005 to 2009. In terms of CD value ranking, from high to low, they are Jiangsu, Shanghai, Zhejiang, Hubei, Chongqing, Hunan, Anhui, Sichuan, Guizhou, Jiangxi, and Yunnan. In terms of trend changes (Figure 4), Jiangxi, Shanghai, and Zhejiang show an upward trend. Sichuan, Guizhou, Yunnan, Chongqing, Hubei, Hunan, Anhui, and Jiangsu all reached their highest CD values in the 2010-2014 period, and then showed a decreasing trend.

The spatial distribution of ED & EP coupling degree (Figure 5) shows that the mean CD values of ED and EP in the eastern YREB (including Shanghai, Jiangsu, and Zhejiang) are higher than 0.9 from 2005 to 2019, and have been leading in the high coupling degree. In addition, provinces in the northern part of the YREB are generally more coordinated than those in the south. Overall, the southern provinces of Yunnan, Guizhou, and Jiangxi have much lower CD values than other provinces in the YREB.

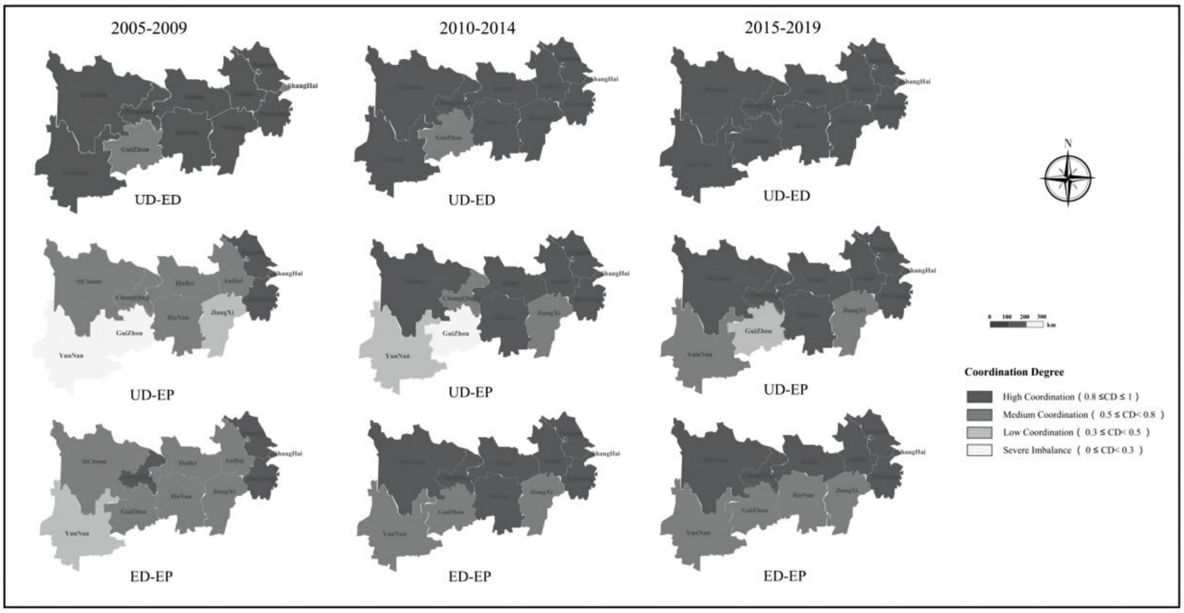

Figure 5. Spatial pattern of the coupling degree of UD&ED, UD& EP, ED&EP of the YREB.

4.1. Coupling Degree of UD&ED& EP

In Table 3, the overall coupling degree results regarding UD&ED& EP for the 11 provinces in the YREB in the three phases of 2005-2009, 2010-2014, and 2015-2019 are derived through the calculation of the coupling degree model.

The overall coupling degree data of the 3 groups of relationships are shown in Table 3. Only Jiangsu has a stable and high coordination level with CD values above 0.9 in all three time periods, and Zhejiang has CD values above 0.8 in all three time periods. Shanghai and Hubei provinces show medium coordination level with CD values below 0.7 in 2005-2009. However, the CD values rose to above 0.84 in 2010-2014 and 2015-2019, with Shanghai's CD value reaching 0.99 in 2015-2019. While the CD values in Jiangxi, Yunnan and Guizhou are much lower, among which, Jiangxi is the lowest with a mean CD value of 0.32, which is low coordination. The CD values of Yunnan and Guizhou are below 0.3, with the mean CD value of Guizhou being 0.1, which belongs to severe imbalance level. Three sets of relationships are ranked in order of mean CD values: Jiangsu, Zhejiang, Shanghai, Hubei, Anhui, Sichuan, Chongqing, Jiangxi, Yunnan, and Guizhou. Except for Jiangsu and Anhui, other provinces in the YREB generally show an upward trend. Among them, the trend of Jiangsu is decreasing, and Anhui has the highest value in the phase of 2010-2014 and then decreasing. (Figure 6)

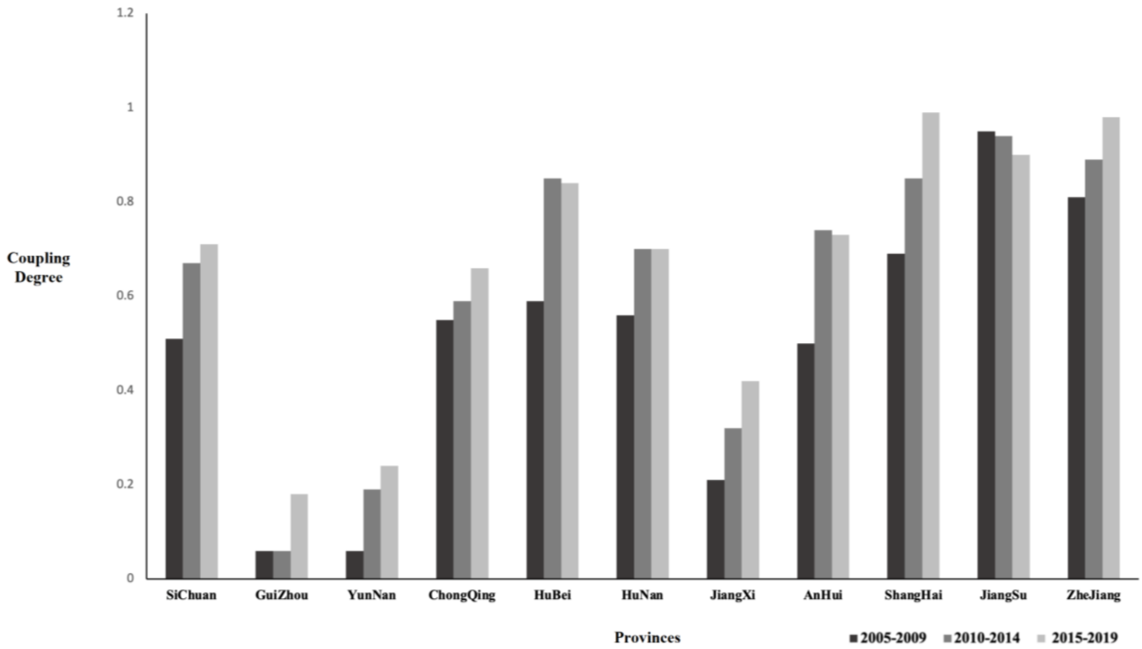

Figure 6. Changes of the coupling degree of UD,ED& EP of the YREB.

The spatial distribution of the overall coupling degree of the three sets of relationships (Figure 7) shows that Jiangsu and Zhejiang in YREB's eastern part have CD values higher than 0.8 in the three time periods 2005-2009, 2010-2014, and 2015-2019, which are in high coordination level for a long time. In the central part of the YREB, Wuhan increases from medium coordination level in 2005-2009 to high coordination level from 2010-2014. Jiangxi rises from a severe imbalance level of CD values below 0.3 in 2005-2009 to a low coordination level starting from 2010-2014. And Yunnan and Guizhou in YREB's western part have CD values below 0.3 in all three time periods, which belong to severe imbalance level.

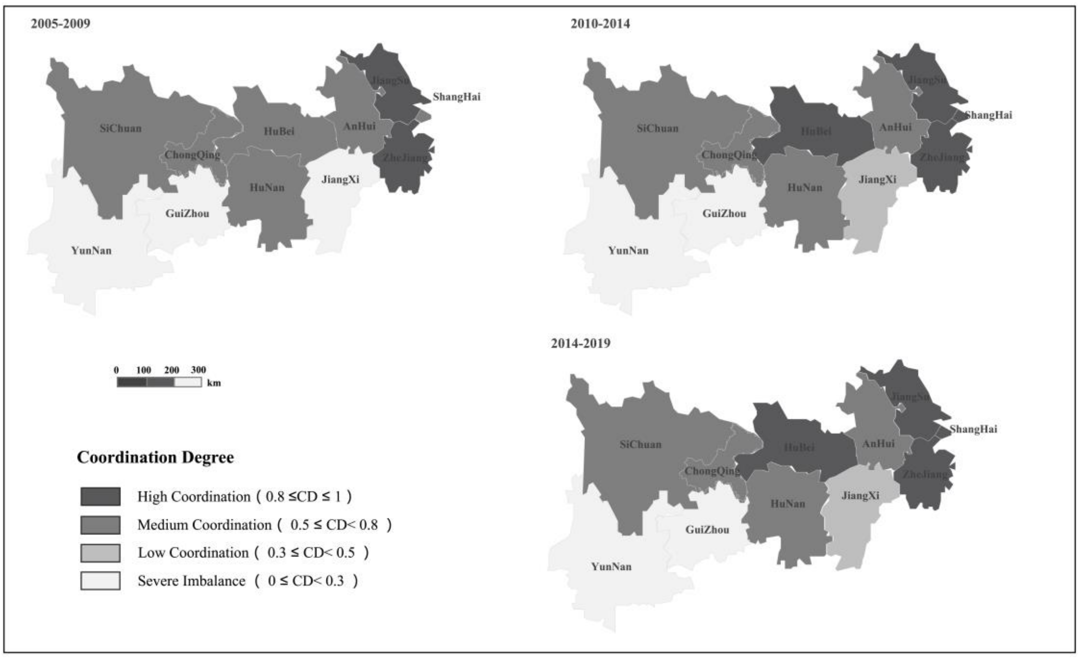

Figure 7. Spatial pattern of the coupling degree of UD, ED & EP of the YREB.

4.2. Coupling Degree of UD&ED& EP&GP

Table 4 presents the results of the overall coupling degree of UD&ED& EP&GP 2005-2019.The results of the data on the overall coupling degree of the four relationships (Table 4) show that Jiangsu, Zhejiang, Hubei, Hunan, Shanghai, and Anhui all have CD values above 0.3 and are all provinces with coordinated development. Among them, Jiangsu has the most prominent CD value of 0.9 or more. The CD values of Jiangxi, Sichuan, Yunnan, Guizhou, and Chongqing are below 0.3 and belong to severe imbalance level. Among them, Guizhou and Chongqing have the smallest CD values of 0.0037 and 0.0001. The provinces in the YREB are ranked, from high to low, as Jiangsu, Zhejiang, Hubei, Hunan, Shanghai, Anhui, Jiangxi, Sichuan, Yunnan, Guizhou, and Chongqing.

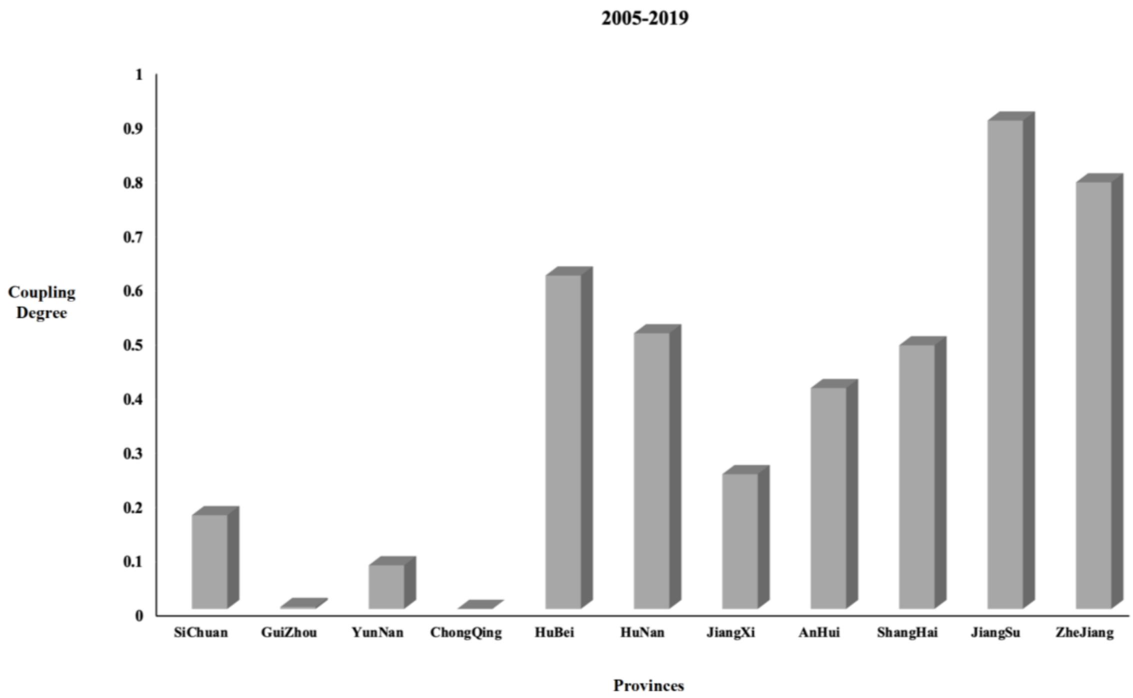

Figure 8. Spatial pattern of the coupling degree of UD&ED& EP&GP of the YREB.

Table 4. Coupling Degree of UD&ED& EP&GP

Provinces	2005-2019				
	ED	EP	UD	GP	CD4
Sichuan	0.3277	0.5538	0.3371	0.1405	0.1731
Guizhou	0.227	0.5509	0.0927	0.9829	0.0037
Yunnan	0.2244	0.6127	0.1445	0.4865	0.0806
Chongqing	0.2979	0.4776	0.2278	0.01	0.0001
Hubei	0.3323	0.4722	0.3195	0.5748	0.6156
Hunan	0.3014	0.5088	0.306	0.233	0.509

Jiangxi	0.2499	0.614	0.2228	0.4497	0.2489
Anhui	0.2874	0.4879	0.3091	0.6465	0.4078
Shanghai	0.4183	0.4596	0.5442	0.2354	0.4868
Jiangsu	0.5915	0.4416	0.5653	0.4966	0.9017
Zhejiang	0.4233	0.4859	0.3915	0.3001	0.7876

The regional distribution of the coupling degree of the 4 relationships (Figure 5 & Figure 8) shows that the coupling centers of the upper, middle and lower reaches of the YREB. And the 3 coupling centers in the order of downstream, midstream and upstream show a gradient difference from high to low. The CD value of Sichuan is 0.1731. Although it still belongs to the severe imbalance level, the upper Yangtze River has Sichuan as the coupling center. The difference between the CD values in Sichuan and Guizhou, which has the lowest CD value in the region, reaches 0.17. The CD value in Hubei is 0.6156, which represents a medium coordination level. In the Middle Yangtze River, Hubei is the regional coupling highland, and the difference in CD values between Hubei and Jiangxi reaches 0.37, while Jiangxi has the lowest CD value in the region with a relatively large gap. Jiangsu is the coupling center in the lower Yangtze River, and the difference between the CD values of Jiangsu and Anhui reaches 0.49, reflecting a huge difference.

5. Discussion

Our research results show that the 11 provinces in the YREB have a high coupling degree between their UD and ED levels, which is corroborated by previous research results based on some cities in the YREB (Han et al., 2019). And in the 3 study periods, there is an overall upward trend. The CD values of all provinces in 2015-2019 have exceeded 0.9, reaching a high coordination level. It is independent of China's economic growth model. When in a period of developing, the benefits of urbanization are self-evident. Local governments can obtain more funds by selling land in order to obtain financial support that promotes economic development and the large number of people pouring into cities can also become a source of demand for land urbanization. Meanwhile, it should be remarked that Guizhou in the upper reaches of the YREB has shown obvious differences from other provinces in the first two stages. The degree of coupling is 30% behind the average level. It shows that urbanization and economic growth are not always synchronized. Guizhou’s experience shows economic growth has limited impact on urbanization.

Our research on urbanization and environmental protection as a whole proves that the coupling degree between urbanization and environmental protection has gradually improved, which is mutually corroborated by the results of existing studies focusing on water environment and urbanization (Pan et al., 2019). Especially after 2015, the environmental protection policy of the central government has changed, and the environmental protection supervision has been significantly strengthened, which has also contributed to a significant improvement in the environment during the period. Shanghai, Jiangsu, and Zhejiang (usually referred to as "Jiangsu-Zhejiang-Shanghai") in the coastal areas of the downstream of YREB have maintained a consistent ultra-high coordination. This area is also often termed as China's "developed" Sector (Zhang & Zhang, 2019). The other regions are different. Hunan and Hubei, located in the midstream of YREB, are clearly behind the Jiangsu-Zhejiang-Shanghai regions. Yunnan and Guizhou, located in the upper stream of the YREB, are even more behind the provinces in the midstream of YREB. What is noteworthy is that Jiangxi Province, adjacent to Jiangsu and Zhejiang, has become a coordinated "low-lying land" in the middle and lower reaches of the YREB. From the specific data on urbanization and environmental protection in Jiangxi Province, the urbanization score of Jiangxi Province is far It is lagging behind the environmental protection score (Lv et al., 2019). It is due to the neighboring developed areas and the siphon effect of super cities, which has caused Jiangxi to lose a lot of resources to support its further development of urbanization. A study on Nanchang (the capital of Jiangxi Province) supports our view. The study found that Nanchang's population urbanization lags behind other provincial capitals, which shows the possible results of our analysis of population loss.

When we analyze the data results of ED & EP, we can also see that the Jiangsu, Zhejiang and Shanghai regions are ahead of other regions. However, there are also many areas where economic development is not coordinated with environmental protection. An explanatory reason is that there is a considerable degree of policy inertia of China's development (Mikalef et al., 2018). In China's urbanization process, the role of the government cannot be ignored. The unitary government has unparalleled executive power in formulating and implementing development plans. Over the past many years, governments at all levels have made rapid GDP development their main task to promote completion, and neglect of environmental protection has come to epitomize China's early development model. But we can also see that Sichuan and Chongqing have become bright spots in the upper reaches of the YREB. The high coordination level between the economic development of these two regions and environmental protection shows that although the scores on the economic development indicators are not high enough, the local government does not adopt a pattern at the expense of the environment.

What is interesting is that, although there is a fairly high coordination level between UD and ED, the coordination level between ED and EP is still generally higher than that of UD and EP. It means although the YREB attaches more importance to environmental protection as the economy develops, the urbanization of this area has not been able to simultaneously adapt to environmental protection.

Examining the development coupling degree of YREB comprehensively on UD, EP and ED, we can clearly find that the level of development coordination within the YREB presents a clear stair-like trend. Specifically, this trend manifests as downstream> midstream> upstream. Within each region, the level of coordination is also different. Hubei Province is clearly ahead of other provinces in the middle reaches of the YREB, Jiangxi Province is clearly behind the surrounding provinces, and the comprehensive coordination of Sichuan and Chongqing in the upper reaches of the Yangtze River is significantly better than Yunnan and Guizhou. The stepped difference in the degree of equilibrium is a manifestation of the uneven development of China's regions. Some studies have comprehensively examined the population, economy, society and spatial urbanization of this region and have also reached a similar conclusion that the eastern part>the central part>the western part (Pan et al., 2019).

Incorporating government behavior into the analysis framework is one of the innovations of this research. According to the above analysis, the government has general economic development pressure and the policy inertia of prioritizing economic development. Then the features of the government's environmental protection policy can be used to measure the government's balance of various development and environmental protection efforts. Since there is often a process from policy promulgation to effective (Ahlers & Schubert, 2015), we did not discuss the relationship between policy and the other three characteristics in stages. Judging from the results, the development strategies of local governments have shown positive intervention in the environment (Guizhou), part intervention (Jiangsu, Anhui, Hubei, Yunnan), a few intervention (Sichuan, Hunan, Shanghai, Zhejiang) and little intervention (Chongqing) four levels. The results of a comprehensive collaborative analysis including government policies show that the trend of downstream> midstream> upstream of the YREB still exists. The trend can also be used to specifically analyze the different strategies adopted by different governments facing development. For example, despite Chongqing and Guizhou comprehensive Collaborative analysis results are very low, their strategic roots are different. Guizhou is due to the environmental protection development strategy selected by the government after 2012, which is far more active than other provinces in environmental protection, while Chongqing is due to policy intervention scores significantly lower than other provinces. It also shows that when analyzing the coupling results of multiple factors at the same time, it is necessary to concern formation strategies instead of only numerical values. According to the research results, potential government intervention strategies are shown in Table 5.

Table 5. Potential government intervention strategies and coordination level.

Urbanization	Economic Development	Environmental Protection	Government Strategic	Coordination
High-level	High-level	High-level	Positive intervention	High-level
			Negative intervention	Low-Level
		Low-Level	Positive intervention	Low-Level
			Negative intervention	Medium
	Low-Level	High-level	Positive intervention	Low-Level
			Negative intervention	Medium
		Low-Level	Positive intervention	Medium
			Negative intervention	Low-Level
Low-Level	High-level	High-level	Positive intervention	Low-Level
			Negative intervention	Medium
		Low-Level	Positive intervention	Medium
			Negative intervention	Low-Level
	Low-Level	High-level	Positive intervention	Medium
			Negative intervention	Low-Level
		Low-Level	Positive intervention	Low-Level
			Negative intervention	High-level

Not all the situations listed in the figure appear in the actual data, so we have predicted some possible results.

We suggest that when formulating development strategies, the government should place more emphasis on balance of various influencing factors to ensure that the environment, economic development and high-quality urban construction can be carried out in a sustainable manner. In particular, the focus is on the guiding role of policy tools to enable the government to be a better balancer in the development process.

6. Conclusions

The study applied the CD model to analyze the coordination between the urbanization development, economic development and environmental protection of provinces in the YREB. Unlike most previous studies that explore the synergy between single factors and urbanization, the research studies the relationship between multiple factors and urbanization development over a longer period of time, including an analysis of their common coordination. The results of the study show that in the 15 years from 2004 to 2019, the coordination of different levels of the provinces in the YREB has been improving as a whole. But we can also find that the coordination is different. The overall coordination analysis results at all levels show the basic characteristics of downstream> midstream> upstream. The economically developed eastern coastal areas still have advantages in coordination compared with the inland areas, which also proves the regional differences in China's development effectiveness from another level. At the same time, the study also found that regional central areas such as Sichuan and Hubei are more coordinated than neighboring areas. It suggests that the usual law does not always work, and regional central cities still have relative advantages. Another contribution of the research is that, taking into account government policies that are rarely involved in previous studies, through the intervention of government environmental policies, a government strategic analysis framework based on comprehensive coordination has been established, which helps us understand and apply the results of various coordinated analyses. Provides inspiration. In the light of government behavior is a key element, it will obviously have an impact on a series of factors including urbanization development, economic development. The specific realization mechanism of the relationship between these elements is not covered in this article, and it can be what we will explore next.

Conflict of interest:No potential conflict of interest was reported by the authors

Data Availability Statement

The datasets analysed during the current study are available in the China National Bureau of Statistics Database and Carbon Emission Accounts & Datasets repository, China City Statistical Yearbook and Provincial Government Websites. The datasets are available publicly and free of charge. Specifically, the data of Urban Population, Proportion of Urban Population, Land Used for Urban Construction as a Percentage to Urban Area, Gross Domestic Product (GDP), Per Capita GDP, Gross Regional Product Index (previous year=100), General Budgetary Local Government Revenue, Per Capita Water Resource, Volume of Industrial Solid Wastes Discharged are available in China National Bureau of Statistics Database at https://data.stats.gov.cn/easyquery.htm?cn=E0103. The data of the area of Total Emissions of Carbon Dioxide are available in Carbon Emission Accounts & Datasets at www.ceads.net. The data of the Area of Land Used for Urban Construction and Green Coverage are in China City Statistical Yearbook at https://navi.cnki.net/knavi/yearbooks/YZGCA/detail?uniplatform=NZKPT. The data of Number of Environmental Policies by province are at https://www.sc.gov.cn/10462/wza2012/zwxx/zwxx.shtml; https://www.guizhou.gov.cn/ztzl/gzsgzhgfxwjsjk/gzsjk/index.html; www.yn.gov.cn/zwgk/; https://www.cq.gov.cn/zwgk/zf xxgkml/szfwj/;https://www.hubei.gov.cn/xxgk/; https://www.hunan.gov.cn/hnszf/xxgk/xxgk.html; http://www.jiangxi.gov.cn/col/col13977/index.html; https://www.ah.gov.cn/public/index.html; http://www.tj.gov.cn/zwgk/;www.jiangsu.gov.cn/col/col76552/index.html; http://www.zj.gov.cn/col/col1229019362/index.html.

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