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Spatiotemporal Differentiation and Driving Mechanism of Coupling Coordination between New-Type Urbanization and Ecological Environment in China

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Abstract: The coupling coordination between new-type urbanization and ecological environment is important for regional sustainable development in China. This study proposes an evaluation index system of new urbanization and ecological environment, and adopts a coupling coordination degree model and a spatial error model to explore the spatiotemporal evolution characteristics and driving factors of the coupling coordination degrees of new-type urbanization and ecological environment in 31 provinces of China from 2010 to 2019. The results show spatiotemporal differences in the overall coupling coordination degree, which has shifted from a mild disorder stage to a near disorder stage over the study period. The spatial distribution of the coupling coordination degrees by province has shifted over time from a pattern of low in the middle and high in both east and west regions to a pattern of stepwise decreasing from east, middle to west regions. The spatial correlation of the coupling coordination degrees is gradually weakening over time. Regional economic development, social security, technological progress, industrial structure, and education input can all contribute to inject strong impetus to the coupled and coordinated development of the two systems. As the development of impetus is still insufficient, it is suggested to pay attention to local conditions, strengthen inter-regional cooperation, and strengthen the superposition effect of multiple driving forces.

Keywords: degree of coupling coordination; ecological environment; new-type urbanization; spatial error model; temporal and spatial differences

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1. Introduction

Urbanization is crucial for a region to realize industrialization and modernization, accompanied by changes in economic structure and population moving from rural to urban areas [1]. However, it is usually realized at the expense of food, ecology, and environment. As the world's most populous country, one of the fundamental problems of China is to ensure food security during the rapid urbanization transformation. Hence, in contrast to the traditional urbanization by "city building movement" (i.e., only caring about the level of urbanization while ignoring issues related to agriculture, ecological environment etc.), China pursues the so-called "new-type urbanization", which is people-oriented, and also takes into account the welfare of farmers in rural areas [2]. The new-type urbanization aims to integrate infrastructure and equalize public services in both urban and rural areas, and is characterized by urban and rural integration, industrial interaction, conservation and intensification, ecological livability, and harmonious development [3]. However, there are usually challenges such as resource shortage and ecological environment deterioration [4]. In this context, it is necessary to explore the spatiotemporal evolution and driving factors of the coupling coordination development of new-type urbanization and ecological environment in China.

Based on a brief literature review (see Section 2), we find that, in the existing studies, the coordinated development of new-type urbanization and ecological environment is typically measured by a single index for new-type urbanization and ecological environment. In our opinion, a single index can hardly describe the comprehensive development level of new-type urbanization and ecological environment, resulting in biased estimation. Furthermore, most previous studies analyzed the coupling coordination between new-type urbanization and ecological environment at a local level such as a province, a certain urban agglomeration, or economic belt, rather than at the national level. In addition, few studies have discussed the driving factors behind the coupling coordination. Therefore, this study establishes a comprehensive and objective evaluation system of new-type urbanization and ecological environment indexes, describes the spatiotemporal evolution characteristics of the coupling coordination level, and discusses its internal and external driving factors, taking into account the spatial interaction of regional systems.

Three related models are adopted in this study. The coupling coordination degree model is used to analyze the coupling coordination relationship between new-type urbanization and ecological environment. The spatial correlation method is adopted to estimate the spatial correlation degree of the coupling coordination between provinces. The SEM is applied to analyze the driving factors of the coupling coordination.

This study has four objectives, as follows. (1) Explain the coupling coordination mechanism between new-type urbanization and ecological environment, and establish an index evaluation system. (2) Analyze the spatiotemporal evolution characteristics of the coupling coordination. (3) Estimate the influence degree of internal and external factors on the coupling coordination degree of the two systems. (4) Provide a reference for policy-making on the coupling coordination development of regional new-type urbanization and ecological environment.

2. Literature Review

The research on new-type urbanization can be traced back to 1966. Dennis [5] first proposed the idea of new-type urbanization, revealing the causes of rapid urbanization in underdeveloped and densely populated countries. In China, new-type urbanization is generally understood as a process of people-oriented, comprehensive, coordinated, and sustainable development, which is realized through urban-rural overall planning and integration [6].

There are studies on the protection of ecological environment as early as in the 1950s. It was noticed that, increasingly, resources were exhausted, and the environment was deteriorating. Hence, some studies [7] discussed how to realize the rapid economic development by rationally utilizing resources and protecting the environment. The relations between urbanization and ecological environment are typically described by the Environmental Kuznets Curve Hypothesis [8]. In 1974, Bolitho [8] first discussed the role of engineers in controlling the environment in the process of urbanization. Subsequently, considerable studies have explored the relationship between new-type urbanization and ecological environment [9].

The studies on new-type urbanization and ecological environment can be summarized in three streams. One stream is theoretical studies on the development path of the coupling of new-type urbanization and ecological environment. New-type urbanization can optimize the ecological environment, and ecological environment protection can provide guidance for new-type urbanization [10]. The development paths of the two are highly unified and complementary to each other [11].

Another stream is the measurement of coupling coordination between new-type urbanization and ecological environment. The measurement has been conducted from the perspectives of countries, provinces, economic belts, and urban agglomerations [12] and from aspects such as temporal and spatial evolution, and trend prediction [13]. Approaches used for the measurement include principal component analysis [14], coupled coordination model [15], and comprehensive response model [13].

The third stream is the analysis of the dynamic factors that affect the coupling coordination. Economic development, scientific and technological investment, advanced industrial structure, and other factors can have different degrees of positive driving effects on the coupling coordination of new-type urbanization and ecological environment [16]. There are many dynamic factors in the coupling coordination and the dynamic development among regions is insufficient and different [17].

Further studies on the coupling coordination are needed from three aspects.

Firstly, existing studies typically adopt a single index to measure new-type urbanization and ecological environment [18]. Since a single index could not describe the comprehensive development of new-type urbanization and ecological environment, it is necessary to establish an index system of new-type urbanization and ecological environment based on the internal requirements of new-type urbanization and ecological environment, as will be done by this study.

Secondly, the coupling coordination relationship between new-type urbanization and ecological environment is typically analyzed at the local level by using the subjective weighting method for index weighting [19]. Hence, the objective weighting method is called for to analyze the coupling coordination of the two systems at the national level, which is illustrated by the case of China in this study.

Thirdly, most of the existing studies address the coupling coordination development level or driving factors in an individual region without taking into account the spatial effects between regions [20]. There is a need to study the coupling coordination development from both spatial and temporal aspects, as this study will do.

3. Coupling Coordination Mechanism

The new-type urbanization is a special stage with Chinese characteristics, which has both the inheritance and the transcendence of history. Ecological environment protection is the premise of the new-type urbanization in China. New-type urbanization and ecological environmental protection also complement each other. The coupling coordination mechanism is shown in Figure 1.

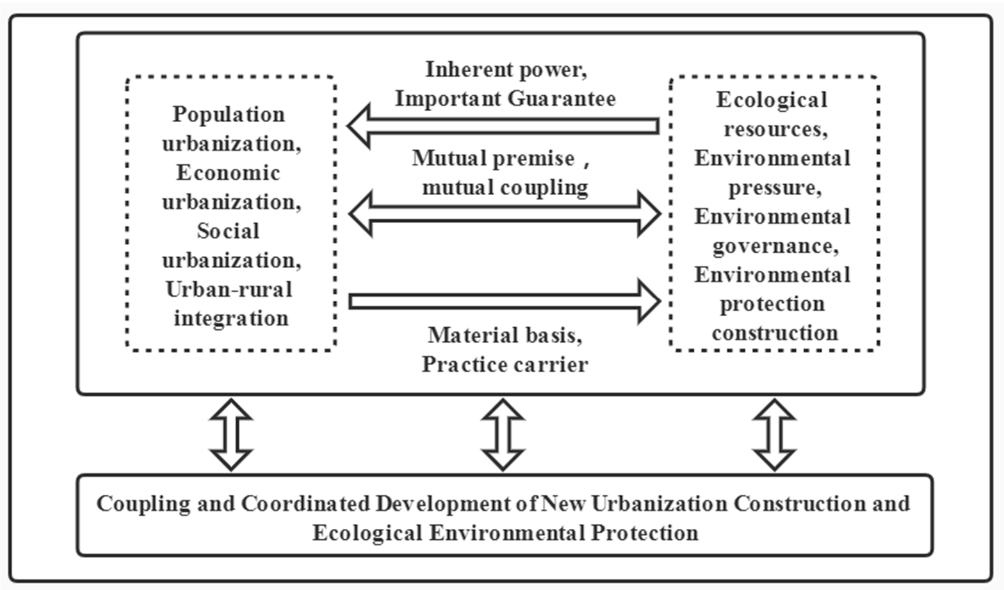

Figure 1. Coupling Coordination Mechanism of New-Type Urbanization and Ecological Environment. Source: own elaboration.

New-type urbanization provides a rich material basis and practical carrier for ecological environment protection. The new-type urbanization emphasizes the realization of urban–rural integration and equal development of public services without sacrificing agriculture, ecology or the environment. Hence, new-type urbanization pays more attention to green, low-carbon, and sustainable development, which can drive the high-speed flow of resource elements; produce a certain siphon effect; promote the accumulation of population, capital, technology, and other resource elements; and lay a solid material foundation for ecological environment protection. New-type urbanization can optimize the development pattern of land space; promote the conservation, intensive use and rational allocation of land, capital, technology, and other resource elements; and promote a green, low-carbon and circular production mode. New-type urbanization promotes the aggregation of regional industries and the centralized supply of infrastructure, which can effectively avoid the low efficiency and high pollution of production caused by the decentralized use of energy, alleviate the stress effect of traditional urbanization on the ecological environment, and promote the process of regional ecological environment protection.

The ecological environment provides an internal driving force and important guarantee for the new-type urbanization. Ecological environment protection can have a restrictive effect on the traditional urbanization development model of inefficient utilization of resources and the adoption of non-equalization basic public services to reduce costs. Strengthening ecological environment protection can maintain the balance of the regional ecosystem, improve the stock and quality of regional resource elements, and realize the generation and regeneration of regional natural resource elements, so as to provide internal power and an important guarantee of the construction of new-type urbanization. The protection of regional ecological environment can drive the development of the regional environmental protection industry and clean energy industry, attract more production factors to such industries, enrich urban industrial formats and create new-type development power for the construction of new-type urbanization. Ecological environment protection is conducive to cultivating excellent ecological culture, and using an awareness of energy conservation and emission reduction, resource conservation, and environmental protection in production and life, so as to improve the quality of new-type urbanization construction. The essence of ecological environment protection is to change the traditional extensive mode of economic development and promote a green economy, circular economy, and low-carbon economy. These development requirements will be reflected in the green innovation of urban traditional industries, enhance the sustainable development ability of urban economy and provide sustainable development power for new-type urbanization.

4. Research Design

In this study, we built an index evaluation system of new-type urbanization and ecological environment, and corresponding data were collected. We then calculated the development indexes of 31 provinces in China from 2010 to 2019 and the coupling and coordination degree of new-type urbanization and ecological environment. Furthermore, in the next two sections, we analyze the spatiotemporal characteristics of the coupling coordination degree and the spatial correlation of coupling coordination degree among provinces. In addition, SEM was used to estimate the internal and external driving factors affecting the new-type urbanization and ecological environment. Finally, we draw conclusions and put forward certain policy suggestions in the last section.

Below in this section, we present the methods we used, data sources, and how the index evaluation system was built up.

4.1. Methods

4.1.1. Data Standardization

The indexes of new-type urbanization and ecological environment used in this study were standardized to eliminate the impact of different dimensions and units [21]. For a positive index (x_{ij}) by time (i) and province (j), we obtained the standardized index (x'_{ij}) by the formula:

$$x'_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \quad (1)$$

where $\min(x_{ij})$ and $\max(x_{ij})$ are the minimum and maximum elements of all the values of the index, respectively. Similarly, for a negative index, to ensure the standardized index was positive, we adopted the formula below:

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

4.1.2. Entropy Method

The evaluation methods for indicators can be divided into subjective evaluation method and objective evaluation method. The subjective evaluation method allows the evaluator to determine the weight and give the score of indicators according to his own experience. On the contrary, the objective evaluation method is to calculate the weight of the index by means of formula according to attributes of indicators. Common objective evaluation methods include analytic hierarchy process and entropy method. Since the entropy method can reduce the deviation caused by subjective factors in the process of weight assignment [22], this study adopted the entropy method to assign weights to each index. Firstly, the proportion of the j index in all indicators of the i province was calculated as follows:

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}.\ (i = 1, 2, 3, \cdots, m; j = 1, 2, 3 \cdots, n) \tag{3}$$

Secondly, the information entropy for the j index was calculated by

$$E_j = -k \sum_{i=1}^{m} P_{ij} \ln(P_{ij}).\quad (i = 1, 2, 3, \cdots, m; j = 1, 2, 3 \cdots, n) \tag{4}$$

where $k = \frac{1}{\ln m} \geq 0$. If $P_{ij} = 0$, then $\lim_{P_{ij} \to 0} P_{ij} \ln P_{ij} = 0$.

Finally, the weight of the j index was calculated by

$$W_j = \frac{1 - E_j}{\sum_{j=1}^{n} 1 - E_j}\ (0 \leq W_j \leq 1) \tag{5}$$

4.1.3. Subsystem Evaluation Model

For each subsystem, the evaluation index was calculated by

$$F_j = \sum_{j=1}^{n} W_j x'_{ij}\ (j = 1,\ 2) \tag{6}$$

4.1.4. Coupling Coordination Degree Model

"Coupling relationship" between two subsystems indicates that the two interrelated systems influence each other, and the feedback mechanism between them determines their evolution process. A coupling model only reflects the degree of interaction and coupling between two subsystems, which is not enough to fully capture their coordinated development state [23]. By contrast, a coupling coordination degree model can effectively analyze the coordinated development level of two subsystems as well as the specific state of each subsystem [24]. Hence, this study adopted the coupling coordination degree model.

The coupling coordination degree (D) of new-type urbanization and ecological environment is calculated by

$$C = \left\{ \frac{F_1 \times F_2}{[(F_1 + F_2)/2]^2} \right\}^{\frac{1}{2}} \tag{7}$$

$$T = \alpha_1 F_1 + \alpha_2 F_2 \tag{8}$$

$$D = \sqrt{CT} \tag{9}$$

where C represents the coupling degree; T is the coordination index between new-type urbanization and ecological environment; and α_1 and α_2 are the undetermined weights of the two subsystems. In the evaluation process, it was considered that the two subsystems were equally important, i.e., $\alpha_1 = \alpha_2 = 0.5$; D is the coupling coordination degree. The coupling coordination degree of new-type urbanization and ecological environment was divided into 10 types [25], as shown in Table 1.

Table 1. Grade Division of Coupling Coordination Degree between New-Type Urbanization and Ecological Environment. Source: modified based on Table 2 in Cao et al. [25].

Coupling Degree of Coordination	Coupling Coordination Degree D Value Interval	Coupling Degree of Coordination	Coupling Coordination Degree D Value Interval
Extreme imbalance	(0.0–0.1)	Barely coordination	[0.5–0.6)
Severe imbalance	[0.1–0.2)	Primary coordination	[0.6–0.7)
Moderate imbalance	[0.2–0.3)	Intermediate coordination	[0.7–0.8)
Mild imbalance	[0.3–0.4)	Well coordination	[0.8–0.9)
On the verge of imbalance	[0.4–0.5)	Quality coordination	[0.9–1.0)

4.1.5. Coefficient of Variation

The coefficient of variation (Cv), also known as the "standard deviation rate", is a statistic that measures the degree of variation of the observed value, and reflects the degree of dispersion on the unit mean [26]. The global test of the coefficient of variation is calculated by

$$Cv = S/\overline{X} \tag{10}$$

where S is the standard deviation of a sample and $\overline{X}$ is the mean of the sample.

4.1.6. Spatial Autocorrelation

Spatial autocorrelation analysis can be used to identify whether there is spatial interdependence between elements in a certain geographical region. A spatial autocorrelation method can be used to test the spatial correlation of the coupling coordination degree of new-type urbanization and ecological environment across provinces [27]. Spatial autocorrelation methods are distinguished by whether a global test (global Moran's I index) or a local test (local Moran's I index) is implemented. The global Moran's I index can detect the distribution characteristics of variable elements that pass the test as a whole and evaluate their sample attributes [28]. The global test formula is:

$$I = \frac{n\sum_{i=1}^{n}\sum_{i=1}^{n} W_{ij}\left(x_i - \overline{x}\right)\left(x_j - \overline{x}\right)}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{IJ}\left(X_I - \overline{X}\right)^2} \tag{11}$$

where $\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$, n is the total number of regional units in the research area, x_i is the variable value of province i, x_j is the variable value of province j, and W_{ij} is the spatial weight matrix.

Local Moran index is used to measure the correlation between the coupling coordination degree of new-type urbanization and ecological environment among provinces [29]. The local test formula is:

$$I_i = \frac{\left(x_i - \overline{x}\right)\sum_{j=1}^{n} W_{ij}\left(x_j - \overline{x}\right)}{S^2} \tag{12}$$

where S is the standard deviation, x_i is the variable value of province i, x_j is the variable value of province j, and W_{ij} is the spatial weight matrix.

4.1.7. Spatial Panel Econometric Model

The spatial panel econometric models mainly include spatial lag model (SLM), spatial error model (SEM), and spatial Durbin model (SDM) [30]. SEM mainly studies the interaction of coupling coordination degree between regions, and measures the impact of the error of coupling coordination degree in adjacent regions on the coupling coordination degree of the region [31]. Its spatial correlation is mainly reflected in the error term. The fixed effect SEM model is specified by

$$\begin{gathered} Lny_{it} = \beta 1LnGDP_{it} + \beta 2LnSOC_{it} + \beta 3LnPAT_{it} + \beta 4LnINDU_{it} + \beta 5LnEDU_{it} + \beta 6LnMAR_{it} + \beta 7LnGOV_{it} + \mu_{it}, \\ \mu_{it} = \lambda W\mu_{it} + \varepsilon_{it} \end{gathered} \tag{13}$$

where i represents the region, t represents the time, y represents the coupling coordination degree, μ represents the random error term vector, W represents the spatial weight matrix, λ represents the spatial correlation error coefficient, and ε_{it} represents random disturbance term of normal independent distribution.

4.2. Data Sources and Index System

4.2.1. Data Sources

This study adopts the data of 31 provinces, municipalities, and autonomous regions in China from 2010 to 2019. The main index data are taken from China Statistical Yearbook from 2011 to 2020, China Statistical Yearbook on Environment from 2011 to 2020, China Energy Statistical Yearbook from 2011 to 2020, and China Rural Statistical Yearbook from 2011 to 2020.

4.2.2. Construction of Index System

The selection of indexes is the basis of study of the coupling coordination of new-type urbanization and ecological environment. The indexes were chosen by referring to the measurement in the literature and considering data availability, operability, and rationality. Following the interpretation of the connotation of new-type urbanization in the National New-type Urbanization Plan (2014–2020), population urbanization, a new-type urbanization evaluation index system, was built including economic urbanization, social urbanization, and urban–rural integration, which were selected as primary indexes [32,33], and are further indicated by 15 secondary indexes. Similarly, an ecological environment evaluation index system was built including the ecological resource conditions, ecological environmental pollution, ecological environmental governance, and environmental protection construction as the primary indexes [34–36], which are further indicated by 13 secondary indexes.

For most secondary indexes, we chose relative variables to eliminate the potential effect of different characteristics across provinces. For example, since ecological resources are scarce, the indexes of ecological resource conditions are represented by relative values per capita to eliminate the effect of different population size across provinces. However, we adopted absolute values for secondary indexes of ecological environmental pollution, since environmental pollution is largely a public good, i.e., everyone is affected by the total pollution scale, rather than the pollution per capita. In addition, the ecological environment governance is largely related to the total ecological environment pollution.

Table 2 shows all the indexes in both index systems. By default, the larger a positive index value is, the more beneficial the index contribution to the coordinated development of the system. For a negative index, the opposite is valid.

Table 2. Evaluation Index System of New-Type Urbanization and Ecological Environment. Data source: China Statistical Yearbook, China Statistical Yearbook on Environment, China Energy Statistical Yearbook, China Rural Statistical Yearbook.

Target Layer	Subsystem Layer	First-level Indicator	Secondary Indicators/Units	Index Direction	References
The level of coupling and coordination between new-type urbanization and ecological environment	New-type Urbanization	population urbanization	urban population density (upd) (people/km^2)	+	[10,12,32,33]
			Urbanization rate of permanent population (upp) (%)	+	[11,32,33]
			Urban registered unemployment rate (urp) (%)	-	[9,12,13,32]
		economic urbanization	Per capita GDP (pg)(CNY/person)	+	[14,15,32]
			The share of secondary industry in GDP (sg) (%)	+	[30–33]
			The tertiary industry's share of GDP (tg) (%)	+	[9,12,16,32]
			per capita disposable income of urban residents (incu) (CNY)	+	[15,26,33]
		social urbanization	Health technicians per 1000 population (hp) (people)	+	[32,33]
			Participation rate of basic endowment insurance for urban and rural residents (pei) (%)	+	[9,11,13,15,32]
			Every 100,000 students in colleges and universities (scu) (people)	+	[13,32,33]
			Road area per capita (rpc) (m^2)	+	[9,16,32,33]
			Number of buses per 10,000 people (nbp) (Tai)	+	[15,32,33]
		Urban-rural integration	Per capita income ratio of urban and rural areas (iur) (%)	-	[16,18,32,33]
			Per capita consumption expenditure ratio of urban and rural residents (eurr) (%)	-	[13,16,32]
			Engel's coefficient ratio of urban and rural residents (ecurr) (%)	+	[15,16,33]
	Ecological environment	ecological resource conditions	per capita water resources (pwr) (m^3/people)	+	[15,18,20,34]
			per capita arable land (pal) (hectares/people)	+	[15,17,34]
			Forest area per capita (fac) (hectares/people)	+	[20,34,35]
		ecological environment pollution	Urban Wastewater Discharge (uwd) (ten thousand cubic meters)	-	[34–36]
			Urban exhaust emissions (uee) (ten thousand tons)	-	[19,20]
			Industrial solid waste emissions (iswe) (ten thousand tons)	-	[15,16,20,35]
			Municipal solid waste removal volume (mwv) (ten thousand tons)	-	[18,20,34]
		Ecological Environment Governance	Urban sewage treatment rate (ust) (%)	+	[17,18,20,35]
			Industrial solid waste utilization (iwu) (ten thousand tons)	+	[15,16,20,36]
			Industrial waste gas treatment capacity (itc) (ten thousand cubic meters/hour)	+	[19,32,36]
			Harmless treatment rate of domestic waste (htw) (%)	+	[17,18,26,34]
		Environmental protection construction	Forest cover rate (%)	+	[18,30,35]
			Environmental pollution control investment as a percentage of GDP (eip) (%)	+	[19,20,36]

5. Analysis of the Coupling Coordination Level

5.1. Identification of Difference Degree

Tables 3 and 4 respectively show the spatial and time variation coefficients of the coupling coordination degree calculated for the 31 provinces in China. The coefficients of spatial variation show a "wave-like" downward trend over time, indicating decreasing difference in the degree of the coupling coordination among provinces year by year. On the other hand, the overall coefficient of time variation of the coupling coordination degree of the 31 provinces in China is 0.152, ranging between 0.019~0.207 at the provincial level. Therefore, it is necessary to analyze the change of the coupling coordination degree between new-type urbanization and ecological environment in the 31 provinces from the perspective of both time and space.

Table 3. Provincial variation coefficient of coupling coordination degree over time.

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Cv	0.196	0.169	0.152	0.169	0.153	0.159	0.160	0.166	0.148	0.143

Table 4. Time variation coefficient of coupling coordination degree in each province.

Province	Cv	Province	Cv	Province	Cv	Province	Cv	Province	Cv
National	0.152	Hainan	0.081	Jiangsu	0.110	Shanxi	0.096	Yunnan	0.113
Beijing	0.073	Heibei	0.082	Jiangxi	0.160	Shanxi	0.052	Zhejiang	0.064
Fujian	0.087	Henan	0.136	Liaoning	0.070	Shanghai	0.019	Chongqing	0.085
Gansu	0.106	Heilongjiang	0.097	Niemenggu	0.074	Sichuan	0.115	Anhui	0.126
Guangdong	0.064	Hubei	0.094	Ningxia	0.060	Tianjin	0.095		
Guangxi	0.110	Hunan	0.093	Qinghai	0.101	Xizang	0.207		
Guizhou	0.161	Jilin	0.093	Shandong	0.074	Xinjiang	0.121		

5.2. Spatio-Temporal Evolution Analysis

The overall development of new-type urbanization is increasing year by year (Table 5). China promulgated the "National New-type Urbanization Plan (2014–2020)" in 2014, which became the turning point of the country's new-type urbanization construction. The policies announced in the document have steadily promoted the development of new-type urbanization. On the other hand, the ecological environment development is "wave-shaped" and relatively slower than the new-type urbanization development. Hence, the coupling coordinated development of new-type urbanization and ecological environment is mainly affected by the ecological environment development. During the study period, the overall degree of the coupling coordination across the country shifted from a stage of mild dissonance to a stage of close to dissonance, and the overall trend was increasing year by year. New-type urbanization not only gives a certain pressure to the ecological environment, but also provides a certain support for the protection of the ecological environment, so that the development and coordination degrees of the two systems are significantly improved over time. Following the pattern, it is possible to achieve the coordinated development of the two systems.

Figure 2 shows the classified coupling coordination degree data of 2010, 2013, 2016, and 2019. In 2010 the coupling coordination degrees of new-type urbanization and ecological environment ranged between 0.274~0.563, with the lowest in Gansu, in the phase of moderate disturbance. The four provinces of Xinjiang, Guizhou, Jiangxi, and Hainan are in the phase of moderate coordination, Guangdong and Xizang are in the phase of force coordination, and the other provinces are in either mild imbalance or the verge of imbalance stages.

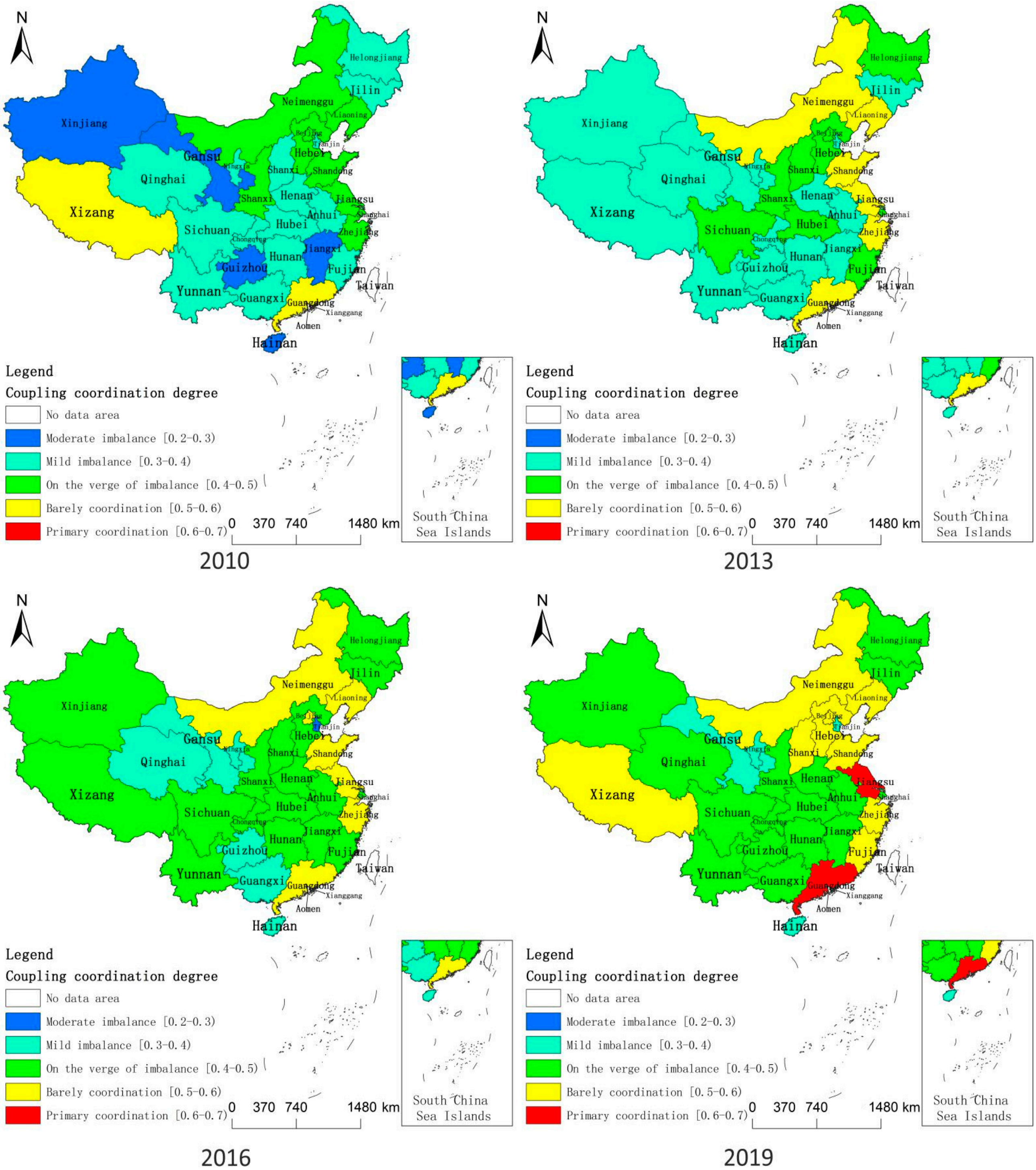

Figure 2. Spatial and temporal distribution of coupling coordination types in 31 provinces in 2010, 2013, 2016, and 2019. Source: map data obtained from the China National Geographic Information Center.

Table 5. Evaluation Index and Coupling Coordination Degree of New-Type Urbanization and Ecological Environment from 2010 to 2019.

Year	New Urbanization Index	Ecological Environment Index	Coupling Coordination (East)	Coupling Coordination (Central)	Coupling Coordination (West)	Coupling Coordination (National)	Classification (National)
2010	0.068	0.093	0.428	0.344	0.360	0.380	Mild imbalance
2011	0.070	0.097	0.443	0.363	0.357	0.389	Mild imbalance
2012	0.074	0.098	0.460	0.391	0.381	0.412	On the verge of imbalance
2013	0.076	0.101	0.473	0.398	0.377	0.416	On the verge of imbalance
2014	0.078	0.101	0.479	0.410	0.398	0.430	On the verge of imbalance
2015	0.080	0.098	0.478	0.424	0.412	0.439	On the verge of imbalance
2016	0.084	0.099	0.483	0.437	0.420	0.447	On the verge of imbalance
2017	0.088	0.109	0.513	0.463	0.452	0.476	On the verge of imbalance
2018	0.091	0.103	0.510	0.474	0.451	0.478	On the verge of imbalance
2019	0.094	0.102	0.519	0.474	0.465	0.487	On the verge of imbalance

In 2013, the coupling coordination degrees remained between 0.31 and 0.545. Provinces in the moderate imbalance stage disappeared, and the number of provinces that were barely coordinated increased. Guangdong had the highest coupling coordination degree, although still in the barely coordinating stage. Compared to 2010, the coupling coordination degrees of the 31 provinces generally increased, although not for all provinces. In particular, Xizang has dropped from a barely coordinated stage to a mild imbalanced stage.

In 2016, the coupling coordination degrees remained between 0.264 and 0.575. Only Tianjin was in the stage of mild imbalance, and the number of provinces that were barely coordinated continued to increase. However, the level of coordination in Shanghai declined.

In 2019, the coupling coordination degrees increased to be between 0.342 and 0.618. Two provinces of Guangdong and Jiangsu reached the primary coordination stage. The number of unbalanced provinces was gradually decreasing, and the number of coordinating provinces was gradually increasing. The overall coupling coordination degree of the two systems showed a ladder decreasing from east, middle to west regions.

During the study period, the coupling coordination degrees of the two systems in most provinces were gradually increasing year by year, and a few provinces showed a fluctuating trend. Among them, the "wave-shaped" changes in Tianjin and the "V-shaped" changes in Xizang were the most obvious. Further examination shows that Tianjin's characteristics are mainly affected by the ecological environment, extensive resource development and utilization, high pressure for high-carbon industry transformation, single industrial structure, and environmental pressure due to population infrastructure [12]. The characteristics of Xizang are mainly affected by the new-type urbanization. Xizang is rich in resources and the economic development and infrastructure construction are relatively backward. Its economic and social development mostly depends on the guidance of the central government, which makes the new-type urbanization construction dependent on the level of the central government attention.

In general, the development of the coupling coordination degree of the two systems varies among different regions. The coupling coordination degree of the eastern region tends to take the lead and realize coordinated development first. The distribution characteristics of the coupling coordination degree of the two systems shifts from a pattern of low in the middle and high in both east and west regions to stepwise decreasing from east, middle to west regions. The main reason for the change is that, before the release of the national new-type urbanization plan, the economy of the eastern region was developed, and the development index of the new-type urbanization was significantly higher than that of the central and western regions. Although restricted by resources and environment, the restriction effect on the coupling coordination degree is not obvious. Under the in-depth implementation of the "Western Development" strategy, the western region has accelerated the construction of new-type urbanization while promoting economic development. However, with the release of the national new urbanization plan and the implementation of the "One Belt and One Road" strategy, the new-type urbanization in the central region has achieved good development, and the economic development plateau in the central region is gradually rising. As a result, the coupling coordination degree has gradually formed a situation of decreasing distribution of "east–central–west" ladder.

5.3. Spatial Correlation Analysis

Stata15 is used to calculate the global Moran's I index of the coupling coordination degree of new-type urbanization and ecological environment in 31 provinces of the country (Table 6). The global Moran's I index increases dynamically from 2010 to 2011 and then keeps decreasing until 2019. Among them, the global Moran's I index in 2011, 2012, 2013 and 2014 passed the significance test at the level of either 10% or 5%. In these years, the coupling coordination degree of the two systems has spatial correlation, although the spatial correlation of the coupling coordination degree is gradually weakening between provinces.

Table 6. Global Moran's I Index of Coupling Coordination Degree between New-type Urbanization and Ecological Environment in 31 Provinces in China.

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Moran's I	−0.024	0.137	0.134	0.192	0.128	0.072	0.071	0.062	0.060	0.022
z-score	0.089	1.566	1.538	2.070	1.484	0.972	0.974	0.901	0.877	0.510
p-value	0.465	0.059	0.062	0.019	0.069	0.165	0.165	0.184	0.190	0.305

Note: *z*-scores are standard deviations, reflecting the degree of dispersion of the data set. The *p* value is a probability to indicate whether the data set was random. The smaller the *p* value, the less likely that the data set was random.

The global Moran's I index can only prove the existence of spatial correlation. To identify the spatial correction of specific provinces, local Moran's I index analysis is required. The local Moran's I index measures the correlation of spatial elements from the local. Here, the local Moran's I index analysis is only carried out for the four years that have passed the significance test of the global Moran's I index. When dealing with the spatial weight matrix, Hainan Province is assumed to connect with two provinces of Guangdong and Guangxi to solve the "isolated island" problem. The LISA clustering results of the 31 provinces are shown in Table 7. The high-high clusters are mostly distributed in eastern coastal provinces such as Zhejiang, Jiangsu, and Shandong, and the low-low clusters are mostly distributed in western regions such as Gansu, Ningxia, and Xinjiang. The stability is weak, and the spillover effect in highly coordinated areas needs to be strengthened. Meanwhile, the proportion of high-high aggregation and low-low aggregation increased from 58.1% in 2011 to 64.5% in 2014, while the proportion of low-high aggregation and high-low aggregation decreased from 41.9% to 35.5%, proving that spatial heterogeneity of the coupling coordination degree of the two systems is weakening, and spatial aggregation is gradually increasing.

Table 7. LISA Clustering Results of the Coupling Coordination Degree of New-Type Urbanization and Ecological Environment in 31 Provinces in China.

Year	H–H Quadrant	L–L Quadrant	L–H Quadrant	H–L Quadrant
2011	Shanghai, Jiangsu, Shandong, Liaoning, Zhejiang, Hebei, Shanxi, Fujian	Guizhou, Gansu, Xinjiang, Guangxi, Qinghai, Hunan, Chongqing, Xizang, Sichuan, Yunnan	Hainan, Jiangxi, Tianjin, Henan, Ningxia, Jinlin, Anhui, Heilongjiang	Neimenggu, Guangdong, Beijing, Shanxi, Hubei
2012	Shanghai, Jiangsu, Shandong, Liaoning, Zhejiang, Hebei, Shanxi, Fujian	Guizhou, Gansu, Xinjiang, Guangxi, Qinghai, Hunan, Chongqing, Xizang, Sichuan, Yunnan, Hubei	Hainan, Jiangxi, Tianjin, Henan, Ningxia, Jinlin, Anhui, Heilongjiang	Neimenggu, Guangdong, Beijing, Shanxi
2013	Heilongjiang, Shanghai, Jiangsu, Shandong, Liaoning, Zhejiang, Hebei, Shanxi, Fujian	Guizhou, Gansu, Xinjiang, Guangxi, Qinghai, Hunan, Chongqing, Xizang, Sichuan, Yunnan, Hubei	Hainan, Jiangxi, Tianjin, Henan, Ningxia, Jinlin, Anhui	Neimenggu, Guangdong, Beijing, Shanxi
2014	Heilongjiang, Shanghai, Jiangsu, Shandong, Liaoning, Zhejiang, Hebei, Shanxi, Fujian	Guizhou, Gansu, Xinjiang, Guangxi, Qinghai, Hunan, Chongqing, Xizang, Sichuan, Yunnan, Hubei	Hainan, Jiangxi, Tianjin, H nan, Ningxia, Jinlin, Anhui	Neimenggu, Guangdong, Beijing, Shanxi

6. Analysis of Driving Factors

6.1. Selection of Driving Factors

The coupling coordination development of new-type urbanization and ecological environment is affected by many factors. Deng [18] believes that economic development, industrial structure, and regional innovation are the internal driving forces to promote the coupling and coordination of ecological civilization and new-type urbanization. Xiong [37] studied the driving factors of new-type urbanization and believed that the endogenous driving force was the development of new-type urbanization, such as social services and industrial structure. Therefore, the driving factors can come from both internal and external aspects. Economic development, social security, technological progress, industrial structure, and educational input [13,38–40] are identified as endogenous driving factors. Market environment and government capacity [16,41], which have indirect effects on the coupling and coordination of new-type urbanization and ecological environment, are taken as external forces. Furthermore, gross national product (GDP) is selected to indicate economic development [38]. The number of health technicians (SOC) is used to indicate social security [13]. The new product sales revenue (PAT) of high-tech industries is used to represent technological innovation [40]. The tertiary industry accounts for the proportion of total GDP (INDU) which is selected to represent industrial structure [39]. The proportion of education fiscal expenditure in total expenditure (EDU) is used to indicate education investment. The amount of foreign direct investment (MAR) is selected to represent market environment [16]. The proportion of fiscal expenditure in GDP (GOV) is selected to indicate government capacity [41]. Table 8 reports the descriptive statistics of logarithm of the variables, since the logarithm can effectively eliminate the adverse effects of dimensions and units on the model.

6.2. Model Test

The spatial correlation analysis above shows significant spatial correlation between the coupling coordination degree of new-type urbanization and ecological environment in 31 provinces. Hence, the spatial econometric model is better than other models in our case [42]. The spatial econometric models are selected through LM test, LR test, and Hausman test.

Table 8. Descriptive Statistics of variables.

	Variable	Obs	Mean	Std. Dev	Min	Max
Internal driving factors	lnGDP	310	9.66	1.00	6.23	11.59
	lnSOC	310	12.16	0.87	9.14	13.58
	lnPAT	310	16.62	1.90	9.78	19.88
	lnINDU	310	3.81	0.20	3.36	4.42
	lnEDU	310	2.77	0.17	2.29	3.10
External driving factors	lnMAR	310	3.76	0.23	2.79	4.08
	lnGOV	310	3.18	0.48	2.36	4.93

Table 9 shows the results of LM test [43]. It can be seen that LM-Error and LM-Lag are significant at the level of 1% and 5%, respectively. RobustLM-Error is significant at the level of 1%. RobustLM-Lag is not significant. Hence, a SEM can better explain the driving factors.

Table 9. LM Test Results for SEM and SLM Selection.

Check Type	LM-Error	LM-Lag	RobustLM-Error	RobustLM-Lag
Statistic (*p*-value)	17.292 (0.000)	4.605 (0.032)	13.132 (0.000)	0.446 (0.504)

As the error items in the SEM may include individual fixed effects and individual random effects, the Hausman test is used to determine the specific effect types (Table 10). It can be seen that the p value is significant, rejecting the original hypothesis. Hence, the LM test and Hausman test suggest the SEM with fixed effects for regression analysis.

Table 10. Statistics of Hausman Test Results for SEM.

Test Summary	Chi2(9)	Prob > chi2
Test	29.26	0.0002

6.3. Empirical Analysis

The SEM is regressed with time fixed effect alone, individual fixed effect alone and both fixed effects, respectively. The regression results are shown in Table 11. By comparison of R^2 and log-likelihood across models, individual fixed effect is identified as significantly better than the other two models of time fixed effect and double fixed effect. Therefore, the SEM of individual fixed effect is selected for result analysis.

The regression results of the individual fixed effect model show that regional economic development, social security, technological progress, industrial structure, and education input all have significant positive effects on the coupling and coordination of new-type urbanization and ecological environment. This shows that strengthening the regional economic strength, improving the social security ability, improving the regional innovation level, promoting the upgrading of industrial structure, and paying attention to improving the level of education can inject strong impetus to the coupled and coordinated development. However, market environment and government capacity have insignificant positive effects, indicating that the driving factors of coupled and coordinated development are not fully developed, and the external forces have not been fully developed. Regression results show that, to promote new-type urbanization and ecological environment of the coupling coordination degree, on the one hand, government should continue to work as a “visible hand” of macroeconomic regulation and control function, and the market as the “invisible hand”, playing a decisive role in the allocation of resources, optimizing the top-level system design, improving the allocation efficiency of market resources, and giving full play to the readjustment of the external power.

Table 11. Regression Results of Coupled Coordination Drivers.

KERRYPNX	OLS Model	SEM		
		Time-Fixed Effect Model	Individual-Fixed Effect Model	Double-Fixed Effects Model
lnGDP	0.3226 *** (8.22)	0.3203 *** (7.40)	0.1075 *** (3.10)	0.1260 ** (2.37)
lnSOC	−0.0481 (−1.37)	−0.0558 (−1.48)	0.1412 ** (2.45)	0.0510 (0.71)
lnPAT	−0.0968 *** (−7.41)	−0.0965 *** (−7.55)	0.0295 ** (2.55)	0.0268 ** (2.34)
lnINDU	0.5833 *** (6.05)	0.5519 *** (5.59)	0.2898 *** (3.70)	0.2535 *** (3.16)
lnEDU	−0.0996 * (−1.92)	−0.1089 ** (−2.05)	0.2459 *** (5.80)	0.3123 *** (5.74)
lnMAR	0.3333 *** (4.93)	0.3361 *** (4.96)	0.0434 (0.57)	0.0596 (0.72)
lnGOV	0.0392 (1.01)	0.0193 (0.43)	0.0218 (0.55)	0.0601 (1.02)
_cons	−0.4889 (−0.81)			
λ		−0.0867 (−0.81)	−0.1277 (−1.36)	−0.1986 ** (−2.11)
sigma2_e		0.0128 *** (12.43)	0.0026 *** (12.42)	0.0024 *** (12.39)
N	310	310	310	310
R^2	0.6001	0.5457	0.7413	0.7299
Log-likelihood		235.8917	484.6967	492.0694

Note: The regression coefficients are the standard errors in parentheses. ***, **, and * indicate significant at the levels of 1%, 5%, and 10%, respectively. The time fixed effect is to solve the problem of missing variables that do not change with individuals but change with time. The individual fixed effect is to solve the problem of missing variables that do not change with time but vary from individual to individual. The two-way fixed effect model solves the problem of time and individual missing variables at the same time. Log-likelihood is a log-likelihood function, and the larger the value of log-likelihood, the better fitness of the model. R^2 is the contribution of the explanatory variables to the sum of squares of the total deviation, emphasizing the quality of the fitness between the models. The larger the R^2, the better the fitness of the model.

6.4. Stability Test

In order to improve the credibility of the empirical analysis, the stability test of the regression results was carried out. The new product sales revenue (Pat) [44] of the high-tech industry was replaced by the number of domestic three patent application authorizations to detect the stability of the spatial variation of the model parameter coefficients. As shown in Table 12, the individual fixed effect SEM was used for estimation, the direction of the regression coefficient has not changed, and the significance is consistent with the regression results. Hence, we conclude that the regression result has good robustness.

Table 12. Stability test of SEM for individual-fixed effects.

KERRYPNX	Estimation of Regression Coefficients	*p*-Value
lnGDP	0.0978 *** (2.71)	0.007
lnSOC	0.1302 ** (2.13)	0.033
lnPAT	0.0326 ** (2.18)	0.029
lnINDU	0.3019 *** (3.79)	0.000

Table 12. *Cont.*

KERRYPNX	Estimation of Regression Coefficients	*p*-Value
lnEDU	0.2366 *** (5.42)	0.000
lnMAR	0.0784 (1.06)	0.291
lnGOV	0.0008 (0.02)	0.985

Note: The regression coefficients are the standard errors in parentheses. *** and ** indicate significant at the levels of 1% and 5%, respectively.

7. Discussion

The level of coupling coordination between new urbanization and ecological environment in 31 provinces in China is increasing over time, and its spatial distribution characteristics in later years show a pattern of stepwise decreasing from east, middle to west regions, consistent with previous studies [45]. However, the regional coupling coordinated development of new urbanization and ecological environment has both similar and different characteristics. For example, in the Yellow River basin regions, the new-type urbanization has developed faster than the ecological environment [12], similar to northeast and southwest China [46,47] and different from the Yangtze river basin regions, where the ecological environment has developed faster than the new urbanization [18]. In the Yellow River basin regions, the coupling coordination degree of the two systems has increased in the early years and then decreased in the later years [12], while it is difficult to discern any pattern for the Yangtze River basin regions [18].

Among the driving factors of the coupling coordination degree of the two systems, economic development level, social security, technological innovation, and education input have significantly positive effects, consistent with previous studies [12,16,17,45]. Our study also shows a different impact of industrial structure and market environment across regions due to imbalanced development of both factors [12,18]. In the eastern coastal regions, the economy has been well developed with much better industrial structure and market environment than the central and western regions. With the proposed policy support from the central government, it is expected that the central and western regions will catch up by adjustment of industrial structure and improvement of market environment.

8. Conclusions and Policy Implications

8.1. Conclusions

Based on the provincial panel data from 2010 to 2019, this study has explored the spatiotemporal evolution and driving factors of the coupling coordination between new-type urbanization and ecological environment in 31 provinces of China.

During the study period, the coupling coordination degree of the two systems in the whole country has improved from a slightly unbalanced stage to a nearly unbalanced stage with spatiotemporal differences. The number of provinces with coordinated development has gradually increased, and most of them are located in the east region. The spatial distribution pattern has shifted from low in the middle and high in both east and west regions to stepwise decreasing from east, middle to west regions.

However, the spatial correlation between the coupling and coordination degree is gradually weakening over time. The spatial fluidity of the coupling coordination between the two systems is weak, and the spillover effect in high coordination areas needs to be strengthened. The clustering of years with spatial correlation shows that the proportion of high-high clustering and low-low clustering is gradually increasing, the spatial heterogeneity of the coupling coordination degree is weakening, and the spatial agglomeration is gradually increasing over time.

Strengthening regional economic strength, improving social security capabilities, enhancing regional innovation levels, promoting industrial structure upgrades, and paying attention to the improvement of education level can inject a strong impetus into coupled and coordinated development of the two systems. However, the coupling coordination degree can be further improved by promoting the impacts of both internal and external factors.

8.2. Policy Implications

Our results indicate that the coordinated development among provinces can be promoted by strengthening interregional cooperation. For example, regional infrastructure can be further shared among neighboring provinces. Similarly, early warning and emergency mechanisms can be shared among neighboring provinces to jointly prevent ecological and environmental pollution. Provincial-level cooperation pilot projects could be carried out to control regional pollution and refine the division of the main functional areas.

Furthermore, system structural contradictions and regional imbalances could be alleviated by adopting reasonable transformation paths and management measures suitable for local conditions. For example, the eastern region could strictly abide by the ecological red line, optimize the spatial pattern of land, alleviate the contradiction between people and land, and cultivate a green ecological space. The central region could continue to consolidate the ecological and green development pattern, accelerate the elimination of backward production capacity, accelerate industrial transformation and upgrading, improve the level of resource intensive utilization, and strengthen the construction of urban infrastructure. The western region could continue to improve the ecological compensation mechanism and promote the effective allocation of different resources across provinces.

In addition, the superposition effect of various driving forces can be enhanced. For example, provinces could improve green development mechanism, share green development achievements, promote the gathering of regional scientific research, and enhance innovation-driven development capabilities. External driving forces can be improved to promote deeper openness.

8.3. Limitations

This study has certain limitations. Due to the data availability, this study only studies the coordinated development of new-type urbanization and ecological environment at the provincial level, and lacks micro-level research on prefecture-level cities and county-level cities. The analysis indicates that coordinated policies can only be formulated from a macro level, and policy formulation lacks pertinence to a single region. In addition, in the driving factor analysis, the differences in driving factors between the east and west regions and the differences in driving factors between the north and south should also be considered. Therefore, the analysis of the coupling and coordinated development of new-type urbanization and ecological environment should be expanded from the perspective of microscopic and different driving factors.

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