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Original Research

Research on the Coordination of Industry and Ecological Environment of the Wanjiang City Belt, China

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Abstract

The Wanjiang City Belt is China's first demonstration zone undertaking industrial transfer. In past decades, rapid industrial development has put great pressure on the ecological environment of this region. Based on symbiosis theory, this study uses the Lotka-Volterra model to measure the coordination level between industrial development and the ecological environment and its spatial distribution in the Wanjiang City Belt from 2011 to 2021. The geographical detector model is chosen to identify the main factors affecting the spatial differences in the coordination level. The results show as follows: (1) The coordination level of industrial development and the ecological environment in the Wanjiang City Belt shows a fluctuating upward trend, but the increase is slight. (2) There are differences in the coordination level of these cities, and the coordination level of most cities has improved slightly or remained at the same level. (3) The main driving factors affecting the spatial distribution of coordination levels are changing, from resource and environmental conditions and industrial development levels to industrial structures, industrial production technology, and environmental protection levels.

Keywords: coordination level, industrial transfer, ecological environment, Lotka-Volterra model, geographical detector model

Introduction

Industrial transfer is of great importance when optimizing industrial spatial distribution and promoting the coordinated development of different areas. Due to resource constraints and significant increases in factor costs, China's eastern coastal areas urgently need industrial transformation to develop high-tech and high-value-added industries. The economic development of China's central and western regions is relatively low. Now, these areas have to transform and upgrade traditional industries and develop new industries.

Given this situation, China established the first national-level demonstration zone for industrial transfer, the Wanjiang City Belt, in 2010. Since then, a large number of industries have been gradually transferred from the Yangtze River Delta region to this area. Establishing the Wanjiang City Belt has been an important measure in implementing a regional

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coordinated development strategy. The region's comprehensive strength has greatly improved since its establishment. Its economic development model has played an exemplary role in the industrial development of the central and western regions. However, the rapid development of industries in the Wanjiang City Belt, while creating obvious economic benefits, has also inevitably posed a threat to the ecological environment. Therefore, this study focuses on the development situation of the Wanjiang City Belt. It evaluates the impact of industrial development on the ecological environment, measures the coordination level between the two systems quantitatively, and identifies the key elements affecting the coordination level. The research results could act as a reference for exploring the new ways and models for undertaking industrial transfer in the central and western regions.

On the whole, in recent years, scholars' research on industrial development and ecological environments has mainly focused on three aspects.

On the one hand, many scholars have analyzed the impact of industrial pollutant emissions and industrial carbon emissions on the environment. Some scholars try to explore measures to reduce pollution and carbon emissions. Yu Hui et al. studied the regional spatial agglomeration characteristics of water pollution-intensive enterprises and the coupling effect with the regional distribution of sewage discharge. They found the four categories of industries with the largest discharge of water pollutants [1]. Zhang et al. systematically analyzed the changes in the quantity and intensity of industrial NOx emissions using the structural decomposition framework and found the driving factors [2]. Li et al. studied the main sources of industrial carbon emissions and then simulated the level of air quality improvement under different carbon peaking scenarios [3]. Temporal variation in industrial CO_2 and local air pollutant emissions was explored by Kang et al., and the key influencing factors and their nonlinear response relationships for industrial pollution reduction and carbon reduction were also identified [4]. Regarding the carbon emission problem of large industrial centers, Vais et al. studied the change in the carbon sequestration capacity of forests near an industrial center in the past 50 years [5]. Alomar et al. used the wavelet-enhanced extreme learning machine to predict CO_2 concentration at different times, which is helpful in planning and implementing carbon emission reduction measures scientifically [6]. Thanapongporn et al. analyzed the impact of participation attitudes, social norms, and low-carbon infrastructure on low-carbon behavior, guiding the development of effective measures [7].

The second research theme relates to the mechanism of industrial development on environmental efficiency: Jiang analyzed the spatial distribution and temporal evolution of environmental efficiency of China's power industry and explored the main factors affecting environmental efficiency by the Tobit model [8]. Pan et al. measured the environmental efficiency and growth rate of the power industry and analyzed the impact of technological progress on the change in environmental efficiency [9]. Liu et al. evaluated the effect of different modes of industrial green transformation on environmental efficiency [10]. Liu (2023) measured the efficiency of industrial green development and explored its spatial distribution [11]. Lan analyzed the mechanism and spatial effect of industrial agglomeration on environmental efficiency in urban clusters [12]. Wang et al. assessed the impact of industrial development on the green efficiency of water resources in the Yangtze River Economic Belt [13]. Deng's research shows that industrial intelligence can significantly promote the improvement of urban green ecological efficiency [14].

The third research direction aims to estimate the coordination degree between industrial development and environmental conditions. Xiang et al. evaluated and compared the coordination level between industrial layout and environmental conditions of China's top ten urban agglomerations and explored the spatial effects of the coordination level based on spatial econometric analysis [15]. Wan et al. revealed the decoupling relationship between industrialization and the ecological environment in coal resource cities and conducted a Granger causality analysis [16]. Zhang et al. analyzed the characteristics of the coupling level between the high-quality development of the industrial economy and ecological environment protection [17]. Chen analyzed the spatial and temporal evolution characteristics of China's industrial green high-quality development level and conducted a spatial correlation analysis [18]. Wang et al. measured the relative and absolute levels of industrial green coordinated development in the Beijing-Tianjin-Hebei city cluster and further identified key obstacle factors [19]. Yin et al. explored the impact mechanism of industrial green transformation on reducing pollution and carbon in resource-based areas [20]. Li Peng et al. studied China's temporal change in green and low-carbon industrial development quality. Green and low-carbon industrial development quality showed an obvious stepped pattern from east to west [21].

These studies quantitatively analyzed the impact of industrial development on the ecological environment from different perspectives. However, existing studies focus more on the change in environmental conditions caused by industrial development but rarely discuss the feedback mechanism of environmental factors to industrial development from the perspective of interaction. Most relevant studies put industrial development and environmental status indicators into a system to calculate the comprehensive assessment index or evaluate the coordination degree of the two systems by decoupling and coupling degree models. Furthermore, regarding the analysis of dominant factors, most studies research the effect of individual influencing factors. This may lead to neglecting the influence of factor interaction to a certain extent. Given the above conditions, this study adopts the Lotka-Volterra model as the evaluation method. The calculation results of this model can not only reflect the coordination degree of industrial development and ecological environment but also show the way and degree of influence between these systems. Therefore, this method can more comprehensively explain interactions between industrial development and the ecological environment. Furthermore, the geographic detector is selected to identify the dominant factors affecting the spatial differentiation of the coordination degree based on the single-factor effect and two-factor comprehensive effect.

Materials and Methods

Study Area

The Wanjiang City Belt, China's first national-level demonstration zone for undertaking industrial transfer, is located in Anhui Province. It is comprised of nine cities, including Hefei, Wuhu, Anqing, and more. This zone is close to the Yangtze River Delta (YRD) region, which is an ideal area for industrial transfer from YRD to central and western China. Now, 80% of the automobile enterprises, 83% of the iron and steel enterprises, 71% of the non-ferrous metal smelting and processing enterprises, and 92% of the household appliance manufacturers in Anhui Province are concentrated in the Wanjiang City Belt, making it an important industrial base in China. In 2021, the population of the Wanjiang City Belt was 61.13 million, and the industrial GDP was 1308.169 billion yuan, which accounted for 53.96% of the total population and 71.84% of the industrial GDP of Anhui Province, respectively. In recent years, the population density of the Wanjiang City Belt has increased continuously, and the urban area has also expanded. However, the amount of industrial waste gas, industrial solid waste, and other pollutants has increased accordingly. It can be known that environmental pollution and ecological destruction have become more and more significant in the process of industrial transfer.

Construction of the Evaluation Indicator System

The evaluation indicator system of the coordination between industry and the ecological environment in the Wanjiang City Belt is constructed based on the Lotka-Volterra and DPSIR models. According to the Lotka-Volterra model, the evaluation indicator system includes 3 target layers, i.e., the industrial development system, the ecological environment system, and the environmental capacity system. Then, combined with the DPSIR model, five criterion layers are designed: D (drive) characterizes the driving factors of industrial development; P (pressure) characterizes the pressure of industrial development on the ecological environment; S (state) characterizes the state of the ecological environment system, which is set as the environmental capacity system in this index system to reflect the supportive capacity of the environment; I (impact) characterizes the impact of industrial development on energy consumption and economic structure, etc.; R (response) characterizes the response measures taken by the society to improve the ecological and environmental conditions. According to data availability, the relevant indicators are selected to construct the evaluation system, and its structure is shown in Table 1.

The research data mainly comes from the Anhui Provincial Statistical Yearbook 2010-2019, the statistical yearbooks of each city, the statistical bulletins of national economic operation and social development of each city, and the bulletins of ecological environment status of each city. Based on the above data, the entropy method is used to get the weight of each indicator (Table 1).

Methods

Entropy Method

The entropy method is an objective method for determining the weight of indicators according to the data's entropy value. The main calculation steps are as follows.

1) Assuming that there are m objects to be evaluated and n evaluation indicators, the evaluation matrix $X = (x_{ij})\ m\times n$, $i = 1, 2, ..., m$, $j = 1, 2, ..., n$, can be constructed, in which x_{ij} is the j-th indicator in the ith year.

2) Normalizing the above matrix

Normalization formula for positive indicators:

$$I_{ij} = (x_{ij} - \min_i\{x_{ij}\})/(\max_i\{x_{ij}\} - \min_i\{x_{ij}\}) \quad (1)$$

Normalization formula for inverse indicators:

$$I_{ij} = (\max_i\{x_{ij}\} - \mathrm{x_{ij}})/(\max_i\{x_{ij}\} - \min_i\{x_{ij}\}) \quad (2)$$

3) Calculating the percentage of the value of the j-th indicator for the i-th evaluation object:

$$P_{ij} = I_{ij} \Big/ \textstyle\sum_{i=1}^{m} I_{ij} \quad (3)$$

4) Getting the information entropy e_j of the j-th indicator:

$$e_j = -\frac{1}{\ln m}\sum_{i=1}^{m}\left(P_{ij}\ln P_{ij}\right), e_{ij} \in [0,1] \quad (4)$$

5) Calculating the weight w_j of the j-th indicator:

$$W_j = (1 - e_j)/\textstyle\sum_{j=1}^{n}(1 - e_j) \quad (5)$$

Table 1. The evaluation indicator system.

Target layer	Criterion layer	Indicator layer	Code	Weight
Industrial development system (F)	D	Population density	X_1	0.066
		Urbanization rate	X_2	0.074
	I	Energy intensity	X_3	0.021
		Proportion of industrial output	X_4	0.054
		Industrial power intensity	x_5	0.067
		Industrial water intensity	X_6	0.019
Environmental capacity system (C)	S	Forest coverage	X_7	0.121
		Per capita green park area	X_8	0.052
		The proportion of urban construction land	X_9	0.034
		Per capita water resources	X_{10}	0.175
		The proportion of cultivated land area	X_{11}	0.119
		The proportion of environmental protection expenditure	X_{12}	0.059
Ecological environment system (E)	P	Carbon emissions intensity	x_{13}	0.029
		Industrial exhaust emission density	X_{14}	0.031
		Industrial wastewater discharge density	X_{15}	0.022
		Industrial solid waste emission density	X_{16}	0.018
	R	Utilization rate of industrial solid waste	X_{17}	0.018
		Treatment rate of domestic sewage	X_{18}	0.020

Lotka-Volterra Model

Symbiosis theory reflects that two species form a symbiotic relationship according to a symbiotic behavior and organization pattern and exchange material, energy, and information. Based on this theory, the relationship between different regional populations can be analyzed [22]. At present, symbiosis theory is widely used in research on urban development, industrial ecology, and so on, and a relatively complete logical framework and analysis method have been constructed [23]. In the 1940s, influenced by symbiosis theory, Lotka and Volterra proposed the interspecific competition model to study the symbiotic relationship between two species in the same ecosystem [24]. The core of the Lotka-Volterra model lies in its differential Equations. These Equations describe temporal changes in the numbers of two species and reflect the growth rate of the species and the interactions between them. According to the theory of this model, the growth of one species may be promoted or inhibited by another species, reflecting the dynamic process of interspecies interaction. Currently, the model has been applied in the research of many fields, such as the competitive relationship between high-speed rail and air express transportation [25], the coordination degree of ecological and economic systems [26], the dynamic competitive relationship between carbon emissions and economic development [27], etc.

With reference to relevant studies, we choose the Lotka-Volterra model to evaluate the coordination degree of industrial development and the ecological environment in the Wanjiang City Belt. In this study, the development level of the industrial system and the state of the ecological environment system are regarded as two types of factors in this region; the environmental carrying capacity is defined as the environmental capacity, and the interaction coefficient of the two types of factors on each other is regarded as the competition intensity coefficient. By the above methods, the industrial system pressure index, the ecological environment system pressure index, and the symbiosis degree index can be obtained to show the coordination degree of the ecological environment and industrial development and analyze the promotion or inhibition effect of the two on each other. The basic form of the Lotka-Volterra model is as follows:

$$\frac{dN_1(t)}{dt} = r_1 N_1(t)\,\frac{K_1 - N_1(t) - \alpha N_2(t)}{K_1} \tag{6}$$

$$\frac{dN_2(t)}{dt} = r_2 N_2(t)\,\frac{K_2 - N_2(t) - \beta N_1(t)}{K_2} \tag{7}$$

Where $N_1(t)$, $N_2(t)$ is the population number of S_1, S_2, respectively, K_1, K_2 is the environmental capacity of S_1, S_2, respectively, and r_1, r_2 is the growth rate of S_1, S_2, respectively. α is the coefficient of competitive intensity of population S_2 to population S_1 and β is the coefficient of competitive intensity of population S_1 to population S_2.

The symbiosis model of the regional industrial development system and ecological environment system can be constructed based on the Lotka-Volterra model, as shown in the following Equations:

$$\frac{dF(t)}{dt} = r_F F(t) \frac{C - F(t) - \alpha E(t)}{C} \tag{8}$$

$$\frac{dE(t)}{dt} = r_E E(t) \frac{C - E(t) - \beta F(t)}{C} \tag{9}$$

Where F(t) represents the development level of the industrial system, E(t) represents the condition of the ecological environment system, C is the environmental capacity, r_F is the growth rate of the industrial system, r_E is the growth rate of the ecological environment system, α is the action coefficient of the ecological environment system on the industrial system, and β is the action coefficient of the industrial system on the ecological environment system.

Equations (10) and (11) can be obtained by discrete transformation from the above two Equations:

$$\mathrm{F(k+1)} - \mathrm{F(k)} = \frac{F(k) - F(k-1)}{F(k-1)} \times F(K) \frac{C(k) - F(k) - \alpha(k)E(k)}{C(k)} \tag{10}$$

$$\mathrm{E(k+1)} - \mathrm{E(k)} = \frac{E(k) - E(k-1)}{E(k-1)} \times E(K) \frac{C(k) - E(k) - \alpha(k)F(k)}{C(k)} \tag{11}$$

From Equations (10) and (11), it can be seen that

$$\alpha(\mathrm{k}) = \frac{\varphi F(k)C(k) - F(k)}{E(k)} \tag{12}$$

$$\beta(\mathrm{k}) = \frac{\varphi E(k)C(k) - E(k)}{F(k)} \tag{13}$$

Where

$$\varphi \mathrm{F(k)} = 1 - \frac{F(k+1) - F(k)}{F(k)} \times \frac{F(k-1)}{F(k) - F(k-1)} = 1 - \frac{r_F(k+1)}{r_F(k)} \tag{14}$$

$$\varphi \mathrm{E(k)} = 1 - \frac{E(k+1) - E(k)}{E(k)} \times \frac{E(k-1)}{E(k) - E(k-1)} = 1 - \frac{r_E(k+1)}{r_E(k)} \tag{15}$$

Based on the above Equations, the industrial system pressure index, the ecological environment system pressure index, and the symbiosis degree index can be defined as Equations (16-18):

$$S_F(k) = -\alpha(k) = -\frac{\varphi F(k)C(k) - F(k)}{E(k)} \tag{16}$$

$$S_E(k) = -\beta(k) = -\frac{\varphi E(k)C(k) - E(k)}{F(k)} \tag{17}$$

$$S(k) = \frac{S_F(k) + S_E(k)}{\sqrt{S_F^2(k) + S_E^2(k)}} \tag{18}$$

Referring to the existing studies [28, 29], the coordination degree level between industrial development and the ecological environment is determined according to the ecological environment system pressure index $S_E(k)$, industrial development system pressure index $S_F(k)$, and symbiosis degree index $S(k)$, as shown in Table 2. The higher the level of coordination, the more harmonious the development between ecological environment and industrial development.

Geographical Detector

Spatial heterogeneity means that the distribution of a geographical phenomenon in different sub-regions is different. The geographical detector is a spatial statistical method for detecting spatial heterogeneity and revealing its driving factors. This method assumes that if an independent variable has a significant effect on a dependent variable, then the spatial distribution of the independent variable and the dependent variable should be similar. The geographic detector can not only evaluate the degree of the spatial differentiation of the dependent variable caused by a single independent variable but also judge the strength and direction of the interaction of two independent variables on spatial differentiation [30].

The geographical detector consists of four parts:

Table 2. Classification of the coordination level of industrial development and ecological environment.

Ecological environment system pressure index	Industrial development system pressure index	Symbiosis degree index	Ecological environment system	Industrial development system	Coordination level
$S_E(k)>0$	$S_F(k)>0$	1<S(k)<	Benefited a lot	Benefited a lot	6
$S_E(k)>0$	$S_F(k)<0$	0<S(k)<1	Benefited a lot	Damaged a little	5
$S_E(k)<0$	$S_F(k)>0$	0<S(k)<1	Damaged a little	Benefited a lot	4
$S_E(k)>0$	$S_F(k)<0$	-1<S(k)<0	Benefited a little	Damaged a lot	3
$S_E(k)<0$	$S_F(k)>0$	-1<S(k)<0	Damaged a lot	Benefited a little	2
$S_E(k)<0$	$S_F(k)<0$	<S(k)<-1	Damaged a lot	Damaged a lot	1

factor detection, interaction detection, risk zone detection, and ecological detection. In this study, we mainly choose factor detection and interaction detection. Factor detection can estimate the extent to which the independent variable (X) explains the spatial heterogeneity of the dependent variable (Y), which is usually represented by the value of q with the following formula:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} \tag{19}$$

Where the value of q ranges from [0, 1], the value of q is positively correlated with the explanatory power of the independent variable on the spatial heterogeneity of the dependent variable. The larger the value of q, the more obvious the spatial differentiation of Y. When q is 1, it means that the independent variable X completely controls the spatial distribution of the dependent variable Y, and when q is 0, it means that there is no relation between X and Y. N denotes the number of samples of the study area, and N_h is the number of samples of the sub-region (h = 1, 2, 3, ..., L). σ^2 and σ_h^2 are the variance of the symbiosis degree index of the study area and the sub-region, respectively.

Based on the results of one-factor detection, interaction detection is further used to identify the explanatory power of the interaction of two factors on the dependent variable. Interaction detection is used to identify whether the interaction of different factors increases or decreases the explanatory power of the dependent variable. The specific steps are as follows: Firstly, calculating the q values of two independent variables (X_1, X_2); second, calculating the q values when the two independent variables interact; and third, comparing the values of $q(X_1)$, $q(X_2)$, and $q(X_1 \cap X_2)$. The effect of interaction contains five types: nonlinear attenuation, one-factor nonlinear attenuation, two-factor enhancement, nonlinear enhancement, and mutual independence. The classification of the above five types is shown in Table 3.

$Min(q(X_1), q(X_2))$ means taking the minimum value in $q(X_1)$ and $q(X_2)$. $Max(q(X_1), q(X_2))$ means taking the maximum value in $q(X_1)$ and $q(X_2)$. $q(X_1)+q(X_2)$ means the sum of $q(X_1)$ and $q(X_2)$. $q(X_1 \cap X_2)$ means $q(X_1)$ and $q(X_2)$ intersect.

Results and Discussion

Temporal Variation of the Coordination Degree between Industrial Development and the Ecological Environment

According to the calculation results, the industrial development index, the ecological environment index, and the symbiosis degree index of the two of the Wanjiang City Belt during 2011-2021 are derived, as shown in Table 4.

During this period, the industrial development index of the Wanjiang City Belt showed an approximate upward trend. From 2010 to 2014, the industrial development index of this region decreased slightly with fluctuation, from 0.132 to 0.102. From 2015 to 2018, the industrial development index had been above 0.147, with a relatively small change. By 2022, the index exceeded 2.00, which increased by 51.51% compared to 2010. During the study period, the regional industrial output value increased by 154.66%, the urbanization rate increased from 53.2% to 65.59%, and a significant decrease in energy intensity and industrial water intensity was achieved. It can be seen that industrial transfer has accelerated the process of industrialization and modernization in the Wanjiang City Belt and promoted the development of industry and the economy of this region.

At the same time, the ecological environment index only increased by 25.18%, and the fluctuation was relatively obvious. The ecological environment index fluctuated repeatedly between 0.141 and 0.088 from 2010 to 2014. It could be seen by analyzing the indicator data that during these four years, the intensity of carbon emissions, industrial waste gas, industrial wastewater, and other emissions in the region was high, and the urban sewage treatment rate was relatively low. From 2015 to 2018, the ecological environment index continued to rise to a peak of 0.22. Almost all the data on industrial pollution indicators showed a downward trend, which was related to the implementation of China's new environmental protection law in 2015 and the comprehensive control of environmental pollution in those years. However, the ecological environment index fell to 0.166 in 2019. This was mainly related to the increase in the emission intensity of industrial wastes and the decrease in the utilization rate of industrial solid

Table 3. The types of interaction between two independent variables.

Standard of classification	Interaction
$q(X_1 \cap X_2) < Min(q(X_1), q(X_2))$	Nonlinear attenuation
$Min(q(X_1), q(X_2) < q(X_1 \cap X_2) < Max(q(X_1), q(X_2))$	One-factor nonlinear attenuation
$q(X_1 \cap X_2) > Max(q(X_1), q(X_2))$	Two-factor enhancement
$q(X_1 \cap X_2) = q(X_1) + q(X_2)$	Mutual independence
$q(X_1 \cap X_2) > q(X_1) + q(X_2)$	Nonlinear enhancement

Table 4. The coordination level of industrial development and ecological environment of the Wanjiang City Belt from 2011 to 2021.

Time	Industrial development index	Ecological environment index	Symbiosis degree index	Coordination level
2010	0.132	0.141	/	/
2011	0.153	0.098	-1.162	1
2012	0.123	0.102	1.128	6
2013	0.111	0.127	-0.569	2
2014	0.102	0.088	-1.244	1
2015	0.156	0.142	0.590	5
2016	0.155	0.182	1.061	6
2017	0.149	0.213	0.479	5
2018	0.147	0.220	-1.027	1
2019	0.194	0.181	-0.145	2
2020	0.215	0.197	-0.506	3
2021	0.206	0.203	-0.090	2
2022	0.200	0.177	/	/

waste. From 2020 to 2022, the ecological environment index first increased and then declined. The main reason for the index's decline was the growth of industrial waste emissions.

From the symbiosis degree index and coordination level perspective, the coordination degree of industrial development and the ecological environment in the Wanjiang City Belt was unstable, showing a continuous M-shaped trend. In 2011-2012, the coordination level increased from level 1 to level 6 and then dropped to level 1 in 2014. From 2015 to 2017, the symbiosis degree index of each year was more than 0, and the coordination level was between 5 and 6. However, in 2018, the coordination level returned to level 1 again. Although the coordination level had increased from 2019 to 2021, it failed to exceed level 3 in those years. In addition, the coordination level in 2021 had increased by only one level compared to 2011. Based on the above analysis, it can be seen that the industrial development of the Wanjiang City Belt is faster than the improvement of environmental quality, and the coordination degree between the two changes greatly.

The National Development and Reform Commission of China has recognized the remarkable results in constructing the Wanjiang City Belt and believes that this region has achieved many achievements in scientific and technological innovation, undertaking industrial transfer, and gathering strategic emerging industries. The rapid development of the Wanjiang City Belt industry benefits from implementing various favorable policies. In 2011, Anhui Province promulgated regulations for promoting the development of the Wanjiang City Belt, which sets the development direction for the region. According to these policies and objectives, the Wanjiang City Belt has introduced many well-known enterprises at home and abroad, laid out a number of major projects of 10 billion yuan, and accelerated the rapid gathering of upstream and downstream enterprises. At the same time, various industrial parks have been set up. The infrastructure and industrial layout in these industrial parks have also been improved. In 2019, Anhui Province was included in the Outline of the Yangtze River Delta Regional Integrated Development Plan, which brought more opportunities for the Wanjiang City Belt to undertake industrial transfer further.

According to the results, the ecological environment quality of the Wanjiang City Belt has also improved as a whole. This is related to the environmental protection policies implemented by the Chinese government in recent years. In 2014, China revised its ecological and environmental protection law. The new law emphasizes the concept of the ecological protection red line and increases penalties for environmental pollution. From 2015 to 2020, the Chinese government formulated a number of major measures to promote ecological civilization and reduce air, water, and soil pollution. Because of these policies and measures, the environmental quality in the study area has been significantly improved. However, it is undeniable that the ecological and environmental problems and risks accumulated in the development process have not been completely solved. The relatively low level of green development and the pursuit of rapid economic growth in some regions means that the unstable state of the ecological environment may still remain.

Spatial Variation of the Coordination Level between Industrial Development and the Ecological Environment

The symbiosis degree index between industrial development and the ecological environment from 2011

Table 5. The coordination level of industrial development and ecological environment in the Wanjiang City Belt from 2011 to 2021.

Time	City								
	Hefei	Chuzhou	Lu'an	Maanshan	Wuhu	Xuancheng	Tongling	Chizhou	Anqing
2011	6	4	6	1	6	4	6	1	2
2012	6	3	4	1	6	5	1	5	1
2013	6	4	4	4	1	3	5	1	2
2014	2	4	1	2	5	3	2	2	1
2015	1	2	2	3	2	2	5	4	5
2016	2	2	1	4	4	2	3	6	3
2017	4	3	2	2	1	4	6	1	6
2018	3	4	2	2	6	1	1	6	3
2019	1	6	2	6	1	6	4	3	6
2020	1	1	1	5	1	1	1	3	5
2021	4	6	2	6	1	6	6	6	2

to 2021 was calculated based on the data of each city. Then, the coordination level of the nine cities in the Wanjiang City Belt was obtained, as shown in Table 5. According to the results, the sequential variation of the coordination level of each city was different.

Compared with 2011, the coordination level of Hefei, Lu'an, and Wuhu had decreased significantly, and the variation range was above 2. Among them, the coordination level of Hefei was at 6 from 2011 to 2013, but it began to decline in 2014. By 2021, the coordination level of Hefei was at 4. As the capital city of Anhui Province and the sub-central city of the Yangtze River Delta city cluster, Hefei has developed rapidly in industry in recent years. Hefei made full use of the location, which connects the east and the west, to introduce a large number of projects. Emerging industries such as chips, integrated circuits, new energy vehicles, and industrial robots constituted a new industrial chain in this city. Hefei thus achieved industrial accumulation rapidly. However, the pressure indexes of the ecological environment system of this city were mostly negative, which indicated that industrial development had a significant negative impact on the ecological environment. The coordination level of Lu'an declined from 6 to 2. Except for 2011, the pressure indexes of the ecological environment system were negative, while the pressure indexes of the industrial development system were mostly positive. The approximate reasons for this situation were as follows: On the one hand, this city accelerated the development of equipment manufacturing, new materials, energy, home manufacturing, and other industries, and the growth rate of industrial added value ranked at the forefront of Anhui Province. On the other hand, the urban construction land expanded significantly, and carbon emissions, industrial solid waste, and other emissions increased, too, but the investment in environmental protection was relatively insufficient. Compared with 2011, Wuhu's coordination level had dropped by 5. For 2019-2021, the coordination level had remained at 1. Wuhu enjoys a good geographical location. Its industrial system and industrial chain were more and more perfect by undertaking industrial transfer and the development of high-tech industries. However, the ecological environment index has shown a downward trend since 2018. The rapid development of industry has resulted in a large increase in the discharge of industrial waste gas and wastewater. At the same time, the proportion of environmental protection expenditure had not increased significantly.

Compared with 2011, the coordination level of Tongling and Anqing had not changed, remaining at levels 6 and 2, respectively. From 2011 to 2021, the coordination level of Tongling was mostly in a good situation, with an average level of 4. The industrial development index of Tongling maintained a small growth trend, but it was lower than the ecological environment index as a whole. At present, this city's pillar industries are still dominated by traditional industries such as copper smelting and processing, fine chemicals, and auto parts, and the radiation effect of industrial transfer is not significant. Overall, the coordination level of Anqing showed a trend of fluctuation. The indexes of ecological environment and industrial development grew slowly, and the situation in which industrial development was being hindered was more obvious in recent years.

The coordination level of Chuzhou, Xuancheng, Maanshan, and Chizhou had all improved. Among these cities, the coordination level of Chuzhou and Xuancheng improved from 4 to 6. From 2011 to 2018, Chuzhou's coordination level was in the range of 2-4 levels. The ecological environment system was negatively affected by industrial development. However, the coordination level has reached 6 twice since 2019. Both indexes of the two subsystems increased, and the growth trend of the ecological environment system was particularly obvious. As for the coordination level of Xuancheng, from 2011 to 2014, the industrial development system was limited by the ecological environment system. However, in 2015-2018, the pressure indexes of the industrial development system became positive, the pressure of the industry on the ecological environment gradually increased, and the coordination level between the two systems decreased in fluctuations. Xuancheng's coordination level was 6 in 2019 and 2021, but contrary to Chuzhou's situation, the growth trend of the city's industrial development was stronger than that of the ecological environment system.

The coordination level of Chizhou and Maanshan increased the most, both being 5. Chizhou was located on the south bank of the Yangtze River. Its landform types were mainly mountains and hills, and the environment was superior. Undertaking industrial transfer made Chizhou's industry develop rapidly. The industrial output value of this area increased by 3 times, and energy consumption intensity and industrial water intensity also decreased significantly. From 2011-2018, the pressure indexes of the ecological environment system of Maanshan were significantly lower than that of the industrial development system. The main reason was that this city had long relied on the iron and steel industry, and successor and alternative industries had not formed yet. The steel industry, with high energy consumption and high pollution, posed a great threat to Maanshan's ecological environment. However, from 2019 to 2021, the coordination level of the city was above 5, and the improvement of the ecological environment was more significant. In recent years, Maanshan has strengthened environmental protection efforts to control water pollution and restore the ecology of mines. In 2019, the Maanshan Municipal Government implemented the "environmental stewardship" project. Through the government's purchase of services, Maanshan employed experts to promote precise and comprehensive management of the ecological environment.

Overall, the coordination level of most cities had improved or remained relatively stable. However, only two cities achieved a substantial increase in the coordination level, indicating that the coordinated development degree of industrial development and ecological environment in most cities had not been significantly improved.

The Main Influencing Factors of the Spatial Variation of the Coordination Level

The factor detection in the geographical detector was used to measure the degree of influence of each indicator in the evaluation system on the spatial variation of the coordination level between industrial development and the ecological environment. Then, interaction detection was used to explore the influence of the interaction between the indicators on the spatial variation of the coordination level.

The factor detection results are shown in Table 6. It can be seen that the influence degree of each factor on the spatial variation of coordination level is different, and the influence degree of some factors changes greatly. In 2011, the top four factors in terms of q-value were per capita green park area (0.952), forest coverage (0.852), industrial power intensity (0.708), and per capita water resources (0.694). These factors mainly belonged to the environmental capacity system, indicating that the resource and environmental endowment of each city were different, which had a great influence on the regional distribution of coordination level. By 2015, the four influential factors with the highest influence degree were carbon emission intensity (0.918), energy intensity (0.714), the proportion of cultivated land area (0.678), and urbanization rate (0.666). These factors reflected that industrial development and urban construction had strongly affected the regional distribution of the coordination level during this period. In 2021, the four factors with the greatest impact were the proportion of industrial output value (0.888), per capita park green area (0.846), industrial water intensity (0.717), and the proportion of environmental protection expenditure (0.720). These factors showed the influence of industrial structure, industrial production technology, and environmental protection level on the regional distribution of coordination level.

Furthermore, compared with 2011, the impact degree of some factors changed greatly: The *q* values of the urbanization rate and the proportion of industrial output value increased by 185.36% and 218.7%. Based on the above analysis, it could be seen that the main influencing factors were constantly changing. In recent years, the continuous decline of industrial output value, the improvement of production technology, the rapid increase of urbanization rate, and the growth of environmental protection input have strengthened the influence on the regional distribution of coordination levels.

Interaction detection was used to estimate whether the combined action of two factors increases or decreases the explanatory power of the dependent variable. We took the data from 2021 for interaction detection, and Fig. 1 shows the results. It could be seen that the influence of the interaction between any two factors was greater than that of a single factor, both of which showed two-factor enhancement or nonlinear enhancement. For example, the factors with low influence degrees, X_{15} (0.188) and X_{10} (0.209), increased their influence degree after interacting with X_{18} and X_{11}, respectively. Their influence degree all exceeded 0.995 in the end. These showed that the spatial variation of coordination level was more due to the interaction of factors, reflecting that the driving mechanism of the factors on the coordination level was complex.

Table 6. The q value of the indexes from 2011 to 2021.

Index	q value										
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
X_1	0.494	0.517	0.799	0.281	0.624	0.370	0.301	0.134	0.399	0.253	0.247
X_2	0.237	0.433	0.383	0.900	0.666	0.606	0.414	0.246	0.402	0.212	0.677
X_3	0.480	0.409	0.276	0.059	0.714	0.391	0.572	0.304	0.720	0.582	0.348
X_4	0.279	0.365	0.368	0.220	0.596	0.507	0.638	0.412	0.412	0.508	0.888
X_5	0.708	0.412	0.337	0.490	0.335	0.669	0.463	0.401	0.075	0.555	0.416
X_6	0.401	0.838	0.727	0.156	0.572	0.645	0.100	0.268	0.119	0.776	0.717
X_7	0.852	0.473	0.737	0.681	0.650	0.666	0.527	0.529	0.747	0.396	0.345
X_8	0.952	0.303	0.274	0.514	0.499	0.298	0.338	0.271	0.660	0.912	0.846
X_9	0.383	0.532	0.389	0.306	0.476	0.394	0.050	0.137	0.461	0.907	0.493
X_{10}	0.694	0.506	0.395	0.931	0.358	0.314	0.440	0.137	0.155	0.404	0.209
X_{11}	0.555	0.678	0.418	0.401	0.678	0.666	0.486	0.311	0.660	0.264	0.360
X_{12}	0.498	0.697	0.395	0.789	0.645	0.912	0.567	0.571	0.346	0.342	0.720
X_{13}	0.544	0.425	0.972	0.408	0.918	0.369	0.233	0.111	0.557	0.563	0.671
X_{14}	0.678	0.544	0.449	0.885	0.392	0.402	0.241	0.460	0.671	0.571	0.243
X_{15}	0.368	0.891	0.668	0.885	0.392	0.402	0.501	0.315	0.505	0.547	0.188
X_{16}	0.324	0.979	0.469	0.353	0.441	0.114	0.255	0.663	0.720	0.546	0.189
X_{17}	0.461	0.287	0.520	0.254	0.521	0.611	0.156	0.307	0.746	0.239	0.687
X_{18}	0.457	0.283	0.384	0.859	0.639	0.162	0.618	0.541	0.220	0.903	0.656

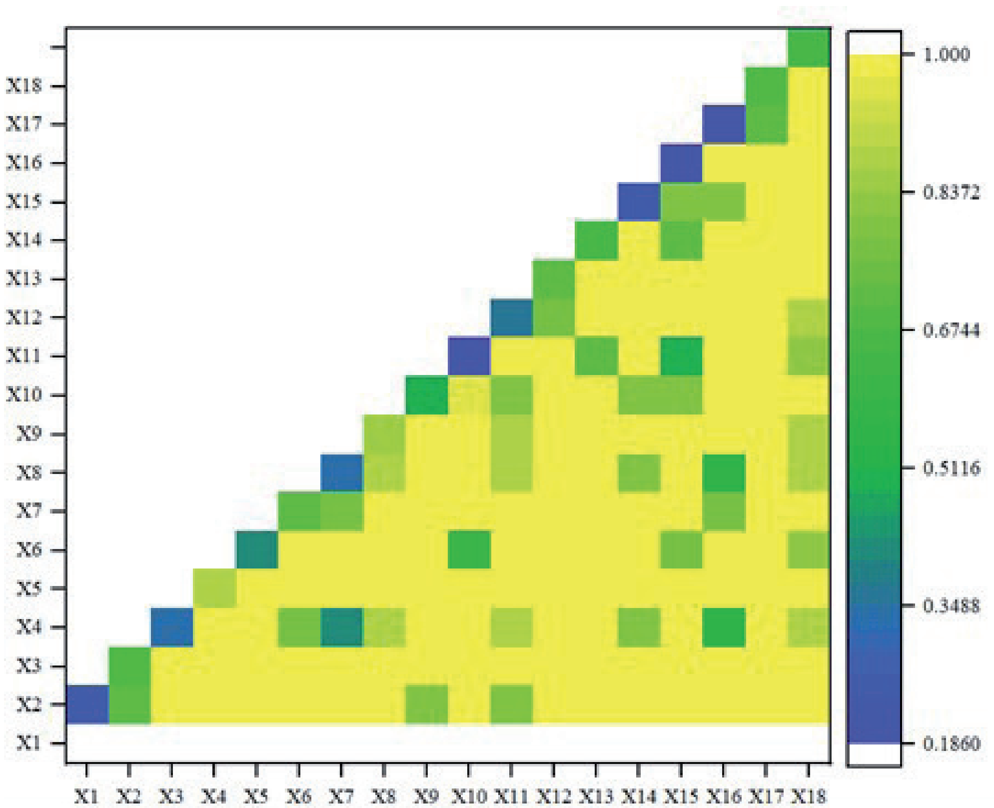

Fig. 1. Interaction detection results.

Conclusions

From 2010 to 2022, the industrial development index of the Wanjiang City Belt increased as a whole, which meant the industrial development situation was good. However, the growth of the ecological environment index was very small, and the index fluctuated significantly. During 2011-2021, the coordination level of industrial development and ecological environment showed a continuous M-shaped change, and the situation of coordinated development had not improved significantly. There were differences in the sequential variation of the coordination level between industrial development and the ecological environment of cities in the Wanjiang City Belt, and the coordination level of most cities improved slightly or maintained the original level. Compared with 2011, the coordination level of Hefei, Lu'an, and Wuhu declined; the coordination level of Tongling and Anqing was maintained at 6 and 2, respectively; the coordination level of Chuzhou and Xuancheng increased by 2 levels, and that of Maanshan and Chizhou increased by 5 levels, and both reached level 6.

Considering the strength of single-factor effects, the factors with greater impacts on the coordination level had changed: in the early stage, they were mainly resource and environmental endowment factors; in the middle stage, factors relating to industrial development mode and urban expansion had a greater impact on the coordination level; and in the late stage, the driving factors were mainly about industrial structure adjustment, industrial production technology improvement, and increment of environmental protection expenditure. The results of interaction detection showed that the influence of any two factors increased after interaction, indicating that the spatial distribution of the coordination level was greater due to the interaction of different factors.

Relevant studies often analyze changes in the environmental state caused by industrial transfer. There is little research on the coordinated development of the economy and environment in the regions undertaking industrial transfer. Zhang et al. found that the coupling degree between industrial transfer and the ecological environment in Henan Province was low, and the environmental system was impacted negatively by industrial development [31]. The studies of Song and Fang showed that the environmental status of the Wanjiang City Belt presented a trend of fluctuating growth, and it has significantly improved since 2015 [32-33]. This is consistent with the conclusion of this study. In the research of the main influencing factors, Ren et al. found that the industrial structure had a very significant impact on the economy and environment of the demonstration areas undertaking industrial transfer [34]. This is similar to the results of the analysis of the driving factors in this research. The study of Zhang Hong et al. also showed that the rationalization of industrial structure played a positive role in the green development of national demonstration zones undertaking industrial transfer [35].

The gradient transfer of regional industries and optimization of productivity distribution are important tasks in China's modernization construction. The achievements and problems in the development of the Wanjiang City Belt could be a reference for further promoting industrial transfer. In order to speed up the adjustment of industrial structure, improve the utilization of resources, and reduce the degree of environmental pollution, some industries with high energy consumption and high pollution may be transferred to areas undertaking industrial transfer. These areas should consider the situation of the region and undertake industries suitable for local resources and environmental conditions in the process of undertaking industrial transfer. At the same time, they should pay attention to protecting the ecological environment of important ecological functional areas, establish evaluation systems for key projects, and strengthen environmental regulations.

The planning of undertaking industries also needs to be further improved, and different key industries should be rationally planned according to the resources and location advantages of different regions. The government should formulate corresponding development plans according to the specific conditions of different cities, design diversified performance evaluation systems, and balance the coordinated development of economic growth and environmental protection.

Based on the analysis of the main driving factors, it can be seen that the main factors affecting the regional differentiation of coordination level are constantly changing. Therefore, it is necessary for policymakers to view the regional coordinated development from the perspective of dynamic changes and to carry out timely assessments in order to determine the priorities of development planning. Meanwhile, the interaction between factors may have a greater impact on the coordination level. Therefore, policymakers should comprehensively consider a variety of measures, including adjusting industrial structure, reducing energy consumption and pollution, increasing environmental protection efforts, improving environmental carrying capacity, optimizing the urbanization level, etc., to promote regional coordinated development.

In addition, there are some discussions about parts of the research methods of this study: The selection of independent variables in the geographical detector model is based on relevant background knowledge so as to identify the factors affecting the spatial heterogeneity of dependent variables more accurately. Therefore, when selecting independent variables, it is necessary to refer to relevant research and consider the characteristics of research objectives and research objects. Furthermore, the independent variables in this model must be categorical variables; that is, the data needs to be classified into pre-defined categories. The classification could be carried out according to relevant background knowledge or by the equal interval method, K-means, and other classification algorithms. It can be known that this model requires more factor selection and classification methods. In order to make the relevant research more scientific and more applicable, the results of different methods can be compared in future research. Similar results can be summarized to evaluate the coordination level more accurately.

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Conflict of Interest

The authors declare no conflict of interest.

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