

Original Research

Evaluation of the Degree of Coordination between Provincial Ecological Protection and High-Quality Development and Diagnosis of Obstacle Factors

Fuxiang Xu*, Hao Xu

School of Public Administration, Shandong Technology And Business University, Yantai 264000, China

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Abstract

Focusing on the major national strategies of ecological protection and high-quality development in the Yellow River Basin, the coupling coordination degree and obstacle degree models were used to analyze and evaluate the evolution of the coupling coordination status and main obstacle factors of ecological protection and high-quality development in Shandong Province from 2009 to 2019, and to predict the development trend of coordination degree in the next four years by combining the GM(1,1) model. The results show that: the level of ecological protection and high-quality development generally showed a trend of gradual improvement during the study period, with the two alternately lagging behind each other; the degree of coupling and coordination continued to improve, and gradually evolved from “friction” to “coordination” with 2017 as the watershed year. The obstacles affecting the coordination of ecological protection and high-quality development vary, with the sub-system level focusing on the state of the ecological environment, economic and social response and economic operation, and indicators such as the proportion of wetland area, fertilizer application and new flood removal area must be paid attention to; the prediction model shows that the coordination of ecological protection and high-quality development in Shandong Province will continue to improve in the next four years but at a slow pace. To this end, it is proposed to deeply understand the relationship between ecological protection and high-quality development, build a tripartite synergy mechanism among subjects, departments and policies, and strive to achieve a positive resonance between the two; and continue to increase ecological protection to create a new growth pole for high-quality development and play a leading role for the rest of the provinces in the Yellow River Basin.

Keywords: ecological protection, high quality development, coupling coordination, degree of obstruction

*e-mail: fxxu@sdtbu.edu.cn

Introduction

The report of the 19th National Congress points out that China's economic development has entered a new normal, and has shifted from a stage of high-speed growth to a stage of high-quality development. The change in the stage of economic development means that the traditional sloppy growth method is no longer suitable for the current development environment with increasing resource and environmental constraints. The development of a low-carbon economy with low energy consumption, low material consumption, low emissions and low pollution characteristics, the control of environmental pollution for ecological remediation, the road to green and sustainable development has become the right thing to do for high-quality development. The Yellow River Basin constitutes an important puzzle for the economic and social development of China with a total area of 795,000 km² covering nine provinces (autonomous regions). The symposium on ecological protection and high-quality development of the Yellow River Basin in Zhengzhou in September 2019 identified a major regional strategy for the economic and social development of the Yellow River Basin. The Yellow River Basin Ecological Protection and High-Quality Development Plan (hereinafter referred to as "the Plan"), which was released in October 2021, reflects the great importance China attaches to ecological protection, environmental management and harmonious and sustainable development of economy and society.

The current research on ecological protection and high-quality development in the Yellow River Basin is intensive, mainly focusing on the interpretation of the connotation, protection and governance, the reality of high-quality development, the level of measurement and correlation analysis. In terms of connotation interpretation, An and Li [1] believes that high quality development should take multiple factors into consideration to build the ecological economic belt of the Yellow River basin, and make efforts in six dimensions: ecological priority, effective market, dynamic energy conversion, industrial support, regional coordination, and people-oriented; Chen and Jin [2] points out that the focus of high quality development in the Yellow River basin should be placed on the whole area coordination, ecological protection, cultural development, and people sharing. In contrast, Jin[3] believes that the coordinated promotion of ecological protection and high-quality development needs to grasp the four major relationships and increase efforts in long-term institutional mechanisms, "three regions and seven groups" synergistic development, industrial upgrading, ecological protection and water conservancy project construction. The ecological protection and high quality development strategy of the Yellow River Basin is rich in connotation and significance, and many scholars have different views, but it has become a basic consensus in the academic community to promote ecological protection and economic development in a coordinated

manner considering economic, social and ecological factors. In terms of protection and governance, it is not only necessary to build a modernized governance system for market, interest, society, culture and ecology [4], but also to deeply grasp the contradictions of the Yellow River in the new era, formulate scientific governance measures, and promote the construction of a governance community and the formation of a benign interaction and multi-governance governance pattern [5]. In terms of the reality of high-quality development, scholars believe that major environmental disasters [6], major ecological and environmental problems caused by the incompatible relationship between water and ecology [7], the backward level of economic material metabolism, inefficient spatial pattern and path dependence [8], and the long-standing "four water problems" of water resources, water ecology, water environment and water disasters "seriously restrict the ecological protection and high-quality development of the Yellow River basin [9], and need to be addressed urgently. As for the horizontal measurement and correlation analysis, entropy power method [10], social network analysis [11] and gray correlation analysis [12] have been widely used, which provide a high value reference for quantitative research on ecological protection and high-quality development in the Yellow River basin. In addition, some other scholars have conducted studies from the perspectives of ecological compensation [13], industrial system [14] and ecological footprint [15], which not only greatly broaden the research horizon but also enrich the strategic connotation. Regarding the research on coupling and coordination, the current studies in the Yellow River basin mainly include ecological protection and high-quality development coupling [16, 17], economy-industry-ecology [18] and socio-economy and ecological environment [19]. In summary, the existing studies show that the research on ecological protection and high-quality development strategies in the Yellow River basin is in a theoretical and methodological explosion, and many scholars try to conduct multidisciplinary cross-sectional research with different perspectives. However, the implementation of the Yellow River strategy requires scientific and rational planning in the nine provinces (autonomous regions) along the Yellow River, as well as research that provides insight into the weaknesses of ecological protection and quality development in the provinces. Therefore, this paper focuses on the ecological protection and high-quality development of the provinces along the Yellow River, introduces a coupling model, takes Shandong province as a sample, and takes the panel data from 2009 to 2019 to carry out an empirical analysis and evaluate the coupling and coordination of provincial ecological protection and high-quality development. The GM (1, 1) model predicts the change trend in the short term, in order to provide a reference for promoting ecological protection and high-quality development in Shandong Province.

Study Area Selection

Shandong Province is an important economic province in the Yellow River Basin and the province where the Yellow River flows into the sea. Creating a pioneering area for ecological protection and high-quality development is the mission given to Shandong Province by the "Yellow River Strategy", and it is the unshirkable responsibility to play the driving role of Shandong Peninsula city cluster in the regional economic growth of the Yellow River basin. Therefore, it is particularly important to grasp the state of ecological protection and high-quality development synergy, and accurately diagnose the relevant factors that hinder the coordinated development. Based on this, the panel data of economic and social development in Shandong Province (2009-2019) are selected to quantitatively study the state changes and causes of the synergy between ecological protection and high-quality development based on the theoretical basis of coupled coordination and obstacle model, and to provide reference for the implementation of the "collaborative promotion of great protection and joint governance".

Material and Methods

Data Sources and Processing

Most of the data in the paper are obtained from provincial statistical yearbooks and official government websites in previous years, namely Shandong Statistical Yearbook, Shandong Ecological and Environmental Status Bulletin, China Statistical Yearbook, China Environmental Statistical Yearbook, as well as EPSDATA and CEInet Statistical Database. For missing data of relevant years, interpolation or trend extrapolation method is adopted to supplement the processing.

Study Design

By constructing the evaluation index system of coupled coordination between provincial ecological protection and high-quality development, the state of each system is scientifically evaluated using the entropy-weighted TOPSIS model with provincial panel data as the data source during the study period. Subsequently, the coupled coordination model is introduced to measure the level of coupled coordination between ecological protection and high-quality development in the provincial area during the study period, and then the obstacle degree model is used to diagnose the change trend of the obstacle degree of the subsystems and each individual indicator affecting the coordination level. Finally, the GM (1, 1) model is used to predict the trend of coupled coordination in the next 4 (years) and to provide policy recommendations in the light of the actual needs of economic and social development.

Evaluation Method

Analysis of the Coupling Mechanism

The term "coupling" is derived from physics and refers to the state or phenomenon in which two or more systems interact and influence each other. The study of the interaction between ecological and economic systems was first published in the 1970s by the famous environmental economist R.M. Solow on the use of natural resources [20]. Later, American scholars Grossman and Krueger [21] proposed the environmental Kuznets curve (EKC), which suggests an inverted "U" shape relationship between economic growth and the environment. It should be noted that the existence of many influencing factors between the two systems and the complexity and diversity of the system itself make the study of the interaction between ecological environment and economic and social development using only linear relationships and single indicators a little thin. Ecosystems provide many goods and services values for human social development (gross ecosystem product GEP), i.e., the conditions and material resources provided by ecosystems and ecological processes for human social activities [22]. These conditions and resources are gradually internalized as power elements in the process of economic and social development, driving the rapid development of economic levels. However, the capacity of the ecosystem to supply, resist disturbance and self-healing is limited in a certain state, and once the rate of economic development exceeds the upper limit of the capacity of the ecosystem, various natural ecological disasters will be triggered [23]. And high-quality development is the development of pursuing quality and efficiency, which is different from the development of pursuing speed and scale in the past. And in the process of development, the change of approach and focus will generate a driving force that is conducive to the evolution of the ecosystem [16], and a good ecosystem will promote the benign development of high quality. Therefore, from the rich connotation of high-quality development, a multi-level index system is constructed to study the coupling relationship between ecological environment and high-quality development. It is of practical significance to grasp the level of regional coupling, take measures to promote coupling and coordination, and promote ecological protection and high-quality development strategies.

Evaluation Indicator System Construction

Based on the connotation of ecological protection and high-quality development strategies, combined with relevant theoretical knowledge and the principles of scientific, systematic and data accessibility of index selection, this paper constructs two sub-system evaluation index systems for ecological protection and high-quality development along the Yellow River province.

The two indicator systems are as follows:

(1) Ecological Protection system. The academic research on ecological protection and governance is quite mature. Among them, the "P-S-R" (pressure-state-response) framework model proposed by OECD (United Nations Economic Cooperation and Development Agency) and the DPSIR and DPESAR models derived from this model have been widely used in the quantitative assessment of ecological security [24-26]. Therefore, this paper is based on the conceptual framework of regionalecological security evaluation index selection and the connotation of P-S-R model proposed by Zuo et al. [27], and the relevant index selection based on the "National Ecological Civilization Construction Demonstration City and County Construction Indicators" released by the Ministry of Ecology and Environment in September 2019. In this way, the ecological protection system takes the ecological protection index as the target layer, and further constructs the indicator layer with the ecological environment state, social development pressure, environmental pollution pressure, and ecological environment response as the quasi-measurement layer. In terms of ecological environment status, considering the ecological community of mountains, water, forests, fields, lakes and grasses and the complexity of ecological environment system, three indicators of forest, wetland and protected area ecology and three indicators of water, soil and air environment are selected, and the frequency of disasters is added to reflect the comprehensive state of ecosystem, totaling seven representative indicators. In terms of social development pressure, the impact of human economic and social development on the ecosystem is taken into consideration, with population, water and energy, and development intensity as representative indicators. For environmental pollution pressure, annual chemical oxygen demand and SO₂ emissions and fertilizer application are selected from three perspectives: water, soil and gas. For ecological response, considering the difference between process and result indicators, new artificial wetland and afforestation, soil erosion control and de-watering area, plus industrial pollution control investment are taken as comprehensive representations respectively.

(2) High Quality Development System. The connotation of high-quality development in the Yellow River Basin is multidimensional, systematic, dynamic and long-term [1]. Not only should we implement the five major development concepts of innovation, coordination, green, openness and sharing, but also grasp the main contradictions of the current economic and social development, consider the integrated development of social, economic, ecological, cultural and living dimensions comprehensively, and realize the people sharing the fruits of development and common prosperity. Therefore, this paper constructs a system of indicators for high-quality development based on the five dimensions proposed by Li et al. [28] on the

evaluation of high-quality development and on the basis of grasping the connotation of the national strategy of ecological protection and high-quality development in the Yellow River basin. It is constructed in five aspects, namely, economic operation, innovation drive, green quality improvement, social progress and living happiness. 1) Economic operation. The primary basis of high-quality economic development lies in whether the economic system can run smoothly and efficiently, so the growth rate of regional and per capita GDP reflects the basic economic growth. The economy of high quality development should not only consider the speed, but also take into account the industrial structure, growth drivers (investment, consumption, net export) and business environment. Therefore, the industrial structure rationality (calculated as the Thiel index), social consumer goods and foreign investment amount to GDP ratio are selected as corresponding proxies, respectively. As for the import and export, due to the complex reasons such as the distribution of global industrial system and international division of labor, processing trade can bring rapid economic growth, but there are problems such as huge energy consumption and serious pollution. The development of service trade and the creation of self-researched technology brands have become the inherent requirements of high quality economic development, so the proportion of processing trade in total import and export is used as the inverse representation. 2) Innovation-driven. One of the main driving forces of high quality development is innovation, and increasing investment in innovation manpower and capital and striving to improve innovation output are the main elements of innovation drive. So the indicators of R&D personnel, funding and high-tech development results are selected to measure. 3) Green quality improvement. Green development is an inherent requirement of high-quality development. According to the content and ideas of the documents on ecological economic indicators such as the "National Ecological Civilization Construction Demonstration City and County Construction Indicators" released by the Ministry of Ecology and Environment on September 11, 2019, and combined with the needs of industrial development, the characterization indicators such as energy consumption per unit of GDP, water consumption and resource recycling are selected. 4) Social progress. Social stability, harmony and positive progress are the environmental guarantee for high-quality development. For this purpose, representative indicators are selected from five aspects: investment in culture, education, science and health, social security, employment, environmental construction, and common prosperity. 5) Living happiness. People's happiness in life is the ultimate goal of high quality economic and social development. The level of high-quality development is characterized by the comparison of urban and rural Engel coefficients and the amount of social public resources enjoyed per capita. Specific indicators are shown in Table 1.

Assign Weights and Calculate Indices

The entropy-weighted TOPSIS model is a multi-objective comprehensive evaluation decision method that combines the advantages of the entropy-weighted and TOPSIS methods and has been widely used in many research areas. The specific operation steps are as follows:

Step 1: Construct the original matrix.

$$X = \{X_{ij}\}_{a \times b} \quad (0 \leq i \leq a, 0 \leq j \leq b) \quad (1)$$

where i represents the year and j represents the indicator. In this way, the following original matrix can be constructed:

$$\begin{pmatrix} X_{11} & \cdots & X_{1a} \\ \vdots & \ddots & \vdots \\ X_{b1} & \cdots & X_{ba} \end{pmatrix} \quad (2)$$

Step 2: Data standardization process. In this paper, the polarization method is used for standardization, and the formula for calculating the positive and negative indicators is:

$$\text{Positive indicators: } x_{ij} = \frac{X_{ij} - X_{ij}^{\min}}{X_{ij}^{\max} - X_{ij}^{\min}} \quad (3)$$

$$\text{Negative indicators: } x_{ij} = \frac{X_{ij}^{\max} - X_{ij}}{X_{ij}^{\max} - X_{ij}^{\min}} \quad (4)$$

Step 3: Assign weights based on the normalized matrix. The calculation formula is as follows:

$$w_j = \frac{1 - e_j}{\sum_{j=1}^b 1 - e_j}, e_j = -\frac{1}{\ln(a)} \sum_{i=1}^a p_{ij} \ln(p_{ij}), p_{ij} = \frac{x_{ij}}{\sum_{i=1}^a x_{ij}} \quad (5)$$

In the above equation, w_j denotes the weight of the indicator, e_j denotes the entropy value of the indicator, and p_{ij} denotes the weight of the indicator characteristics. In addition, the weighting process is made $\ln(0) = 0$ for the convenience of calculation.

Step 4: Construct the weighted normalization matrix Y . That is, the original matrix is multiplied by the indicator weights and calculated as follows:

$$Y = \{Y_{ij}\}_{a \times b} = \{X_{ij} \times w_j\}_{a \times b} \quad (6)$$

Table 1. Provincial ecological protection and high-quality development coupling and coordination evaluation index system.

Target layer	Guideline layer	Indicator layer	Code	Attribute	Weights
Ecological Protection	Ecosystem Status (E1)	Forest cover /%	X1	+	0.0859
		Wetland area share /%	X2	+	0.1379
		Area share of nature reserves /%	X3	+	0.0146
		I, II, III water quality ratio /%	X4	+	0.0357
		Soil and water harmony /%	X5	-	0.0418
		PM10 annual average concentration value /ug/m ³	X6	+	0.0174
		Frequency of natural ecological disasters /times/year	X7	-	0.0411
	Social development pressure (E2)	Population density/person/km ²	X8	-	0.0435
		Regional development intensity/%	X9	-	0.0750
		Water resources development and utilization intensity/%	X10	-	0.0226
	Environmental pollution pressure (E3)	Chemical oxygen demand annual emissions / million t	X11	-	0.0507
		SO2 annual average emissions / million t	X12	-	0.0535
		Fertilizer application amount / million t	X13	-	0.0937
	Economic and social response (E4)	New artificial wetland area / million hm ²	X14	+	0.0616
		New artificial forestation area / million hm ²	X15	+	0.0312
		New soil erosion control area/thousand hm ²	X16	+	0.0420
		New flood removal area/thousand hm ²	X17	+	0.1141
		Industrial pollution control investment / billion yuan	X18	+	0.0377

Table 1. Continued.

High Quality Development	Economic Operation (H1)	Regional GDP growth rate/%	X19	+	0.0388
		GDP per capita growth rate/%	X20	+	0.0433
		Rationalization of industrial structure*/-	X21	-	0.0325
		The proportion of retail sales of social consumer goods to GDP/%	X22	+	0.0702
		Processing trade as a proportion of total import and export/%	X23	-	0.0340
		Foreign investment in GDP/%	X24	+	0.0276
	Innovation-driven (H2)	R&D personnel equivalent full-time equivalent/person-year	X25	+	0.0317
		R&D investment intensity/%	X26	+	0.0311
		High-tech industry main business income as a proportion of GDP/%	X27	+	0.0325
		Number of effective patents/piece	X28	+	0.0435
	Green Quality (H3)	Energy consumption per unit GDP/tons of standard coal/yuan	X29	-	0.0362
		Water consumption per unit of GDP / cubic meter / million yuan	X30	-	0.0325
		Comprehensive utilization rate of general industrial solid waste/%	X31	+	0.0694
		Comprehensive utilization intensity of agricultural waste*/%	X32	+	0.0449
	Social Progress (H4)	Fiscal expenditure intensity of culture, education, science and health/%	X33	+	0.0360
		Medical insurance coverage rate/%	X34	+	0.0947
		Multiplier difference between urban and rural per capita disposable income	X35	-	0.0320
		Unemployment rate/%	X36	-	0.0364
		Harmless treatment rate of domestic waste/%	X37	+	0.0389
	Happy life (H5)	Difference between urban and rural Engel coefficient	X38	-	0.0226
		Number of health technicians per 1,000 people/person	X39	+	0.0448
		Number of books per capita/volume	X40	+	0.0668
		Urban road area per capita/m2	X41	+	0.0270
		Park green space per capita/m2	X42	+	0.0327

Note: The specific calculation formulas of the indicators marked with * in the table refer to relevant studies [29, 30]. It should also be noted that the number of natural ecological disasters is represented by the sum of the number of geological disasters (mudslides, collapses, etc.), forest fires and environmental pollution due to incomplete data.

Step 5: Determine the positive and negative ideal solutions Y^+ , Y^- , and calculate the Euclidean distances L^+ , L^- . The calculation formulae are respectively as follows:

$$\begin{cases} Y^+ = (Y_1^+, Y_2^+, Y_3^+, \dots, Y_b^+) = \{\max Y_{ij} | j = 1, 2, 3, \dots, b\} \\ Y^- = (Y_1^-, Y_2^-, Y_3^-, \dots, Y_b^-) = \{\min Y_{ij} | j = 1, 2, 3, \dots, b\} \end{cases} \quad (7)$$

$$L_i^+ = \sqrt{\sum_{j=1}^b (Y_j^+ - Y_{ij})^2}, L_i^- = \sqrt{\sum_{j=1}^b (Y_j^- - Y_{ij})^2} \quad (8)$$

In the above equation, Y^+ and Y^- respectively represent the maximum and minimum values of the j th indicator in the i th year, and L^+ and L^- respectively represent the distance of the j th indicator from Y^+ and Y^- ,

Step 6: Calculate the posting progress C_i , and express the score of each system in each evaluation year by posting progress, and the larger value indicates the higher level of each system. The calculation formula is:

$$C_i = \frac{L_i^-}{L_i^+ + L_i^-}, C_i \in [0, 1] \quad (9)$$

Coupling Coordination Degree Model

The coupling degree function was used to calculate the interaction state index between the two systems of ecological protection and high-quality development, and the relative development degree was expressed by comparing the respective scores of the two systems, and the coupling coordination degree model was introduced to calculate the coupling coordination degree between the two systems during the study period. Referring to the existing research results [31], this paper respectively defines the calculation formulae as follows:

$$C = \frac{2\sqrt{E \times H}}{E + H} \quad (10)$$

$$R = \frac{E}{H} \quad (11)$$

$$\begin{cases} T = [(\alpha \times E) + (\beta \times H)] \\ D = \sqrt{C \times T} \end{cases} \quad (12)$$

In the above equation, C represents the coupling degree, R represents the relative development degree. T is the level of comprehensive coordination between systems, combined with the understanding of the connotation of ecological protection and high-quality development strategy, and take the equivalent value of 1/2. D represents the coupling coordination degree, according to the actual situation and combined with

related research [32], the coupling coordination degree of provincial ecological protection and high-quality development is subdivided into three stages and nine types (see Table 2).

Barrier Degree Model and GM(1, 1) Prediction Model

(1) Barrier degree model. In order to clarify the direction and force points for the synergistic promotion of provincial ecological protection and high-quality development, the reasons for the change of synergy degree during the study period were explored. The barrier degree model was used for identification, and the calculation formula was defined with reference to relevant studies [33] as:

$$O_{ij} = \frac{(1 - X'_{ij}) \times w_j \times 100\%}{\sum (1 - X'_{ij}) \times w_j}, O_i = \sum O_{ij} \quad (13)$$

In the above equation, O_{ij} denotes the barrier degree of single indicator within subsystem i to the synergy degree of provincial ecological protection and high-quality development, O_i denotes the barrier degree of subsystem i to the synergy degree, X'_{ij} denotes the value of single indicator after standardization, and w_j denotes the weight of indicator.

(2) GM(1, 1) prediction model. The evaluation results of the synergy between provincial ecological protection and high-quality development were obtained by calculation, and the GM (1, 1) gray prediction model

Table 2. Classification of stages, states and types of coupling and coordination between ecological protection and high-quality development in the province.

Coordination degree	Relative development degree	Coordination development stage	Coordination development characteristics	Coupling coordination type
0 < D < 0.5	0 < R ≤ 0.8	Antagonism	Ecological protection lags behind, both are highly antagonistic	I
	0.8 < R ≤ 1.2		Synchronized development, low antagonism between the two	II
	1.2 < R		High-quality development lags, both highly antagonistic	III
0.5 < D < 0.7	0 < R ≤ 0.8	Abrasion	Ecological protection lagging, low degree of friction between the two	IV
	0.8 < R ≤ 1.2		Synchronous development of the two, high degree of friction	V
	1.2 < R		High quality development lagging, low friction between the two	VI
0.7 < D ≤ 1	0 < R ≤ 0.8	Coordination	Lagging ecological protection, low coordination between the two	VII
	0.8 < R ≤ 1.2		Synchronous development of the two, high coordination	VIII
	1.2 < R		High quality development lagging, low coordination between the two	IX

was used to predict the trend of synergy changes in the next four years, and to provide policy recommendations for the integrated promotion of ecological protection and high-quality development, and the promotion of comprehensive, coordinated and sustainable economic and social development. The specific modeling method refers to the study of Sun [34], and the prediction model is set as follows:

$$\hat{X}^{(1)}(q) = \left[X^{(0)}(1) - \frac{u}{a} \right] e^{-a(q-1)} + \frac{u}{a}, \quad q = 1, 2, \dots, n \quad (14)$$

1) In the above equation, $\hat{X}^{(1)}(q)$ is the new sequence after one accumulation of the original sequence, the original sequence and the new sequence can be tabulated respectively as:

$$\begin{cases} X^{(0)} = \{X^{(0)}(p), p = 1, 2, \dots, n\} \\ X^{(1)} = \{X^{(1)}(q), q = 1, 2, \dots, n\} \end{cases} \quad (15)$$

2) In the above equation, \hat{a} is set to be the parameter variable to be estimate $\hat{a} = [a, u]^T$, a represents the development gray and u represents the endogenous control gray number, which is calculated by the least squares method to obtain: $\hat{a} = (B^T B)^{-1} B^T Y_n$. B and Y_n are calculated as follows:

$$B = \begin{bmatrix} -\frac{1}{2}(X^{(1)}(1) + X^{(0)}(2)) & 1 \\ -\frac{1}{2}(X^{(1)}(2) + X^{(0)}(3)) & 1 \\ \vdots & \vdots \\ -\frac{1}{2}(X^{(1)}(n-1) + X^{(0)}(n)) & 1 \end{bmatrix}, Y_n = (X^{(0)}(2), X^{(0)}(3), \dots, X^{(0)}(n))^T \quad (16)$$

Results and Discussion

Analysis of Time Series Changes in Ecological Protection and High Quality Development Index

Using the above entropy TOPSIS model to calculate the level of both systems of ecological protection and high-quality development in Shandong Province from 2009 to 2019, the calculation results are shown in Fig. 1. From Fig. 1, the levels of both ecological protection and high quality development systems in Shandong Province show a trend of gradual improvement during the study period. Among them, the ecological protection subsystem has the development status of "first decreasing, then increasing", while the high-quality development system shows the change status of "first fast, then slow".

According to the time-series change curve of ecological protection level, it can be roughly divided into three stages. In the first stage (2009-2012), the ecological protection level changed slowly and tortuously. Firstly, the level of ecological protection increased from 0.4642 in 2009 to 0.4682 in 2010, then decreased to 0.4448 in 2011, and then slowly climbed to 0.4522 in 2012. The analysis found that this period is the "Eleventh Five-Year Plan" and "Twelfth Five-Year Plan" alternate to undertake important years. On the one hand, there is a high pressure from the state to reduce the emissions of major pollutants during the Eleventh Five-Year Plan. On the other hand, the level of attention to environmental protection began to gradually increase, and the importance of ecological protection to economic and social development was enhanced through institutional reform and legislative planning. In the second phase (2012-2015), the decline was greater, from 0.4096 in 2013 to 0.3247 in 2015, the lowest value ever. This is related to the pressure brought by rapid economic and social development and the tilt of government priorities within this stage. In the third phase (2015-2019), the level of ecological protection steadily improved and reached 0.4699 in 2019, the highest value in the study period. This is due to the increase in environmental pollution control and the acceleration of natural ecosystem restoration and construction in Shandong Province during the 13th Five-Year Plan. The "13th Five-Year Plan" clearly points out that "strengthen the prevention and control of water, air and soil pollution, ... the implementation of the strictest environmental protection system; accelerate the improvement of multi-level, into a network, functional composite of the basic ecological system."

The chronological changes of the high quality development system are obvious, with 2015 as the dividing line, the growth rate is larger before 2015, and then the overall decrease in speed. Careful observation found that the magnitude of change relatively coincides with the "Eleventh Five-Year Plan", "Twelfth Five-Year Plan", "Thirteenth Five-Year Plan" period development characteristics. The first is the end of the Eleventh Five-Year Plan (2009-2010), the level of high-quality development is a small increase from 0.3146 in 2009 to 0.3539 in 2010, which is affected by the global economic crisis, economic growth is in a low-speed stage. The large-scale investment plan and the implementation of new economic growth poles such as the Development Plan for the Yellow River Delta Efficient Ecological Economic Zone and the Development Plan for the Blue Economic Zone on the Shandong Peninsula have largely stabilized the maintenance of high-quality economic and social development. Second, during the 12th Five-Year Plan period, the speed of high-quality development alternated between fast and slow, from 0.4110 in 2011 to 0.6924 in 2015 and reached its peak. On the one hand, thanks to the stable and rapid growth of economic development. The average annual growth rate of GDP in Shandong

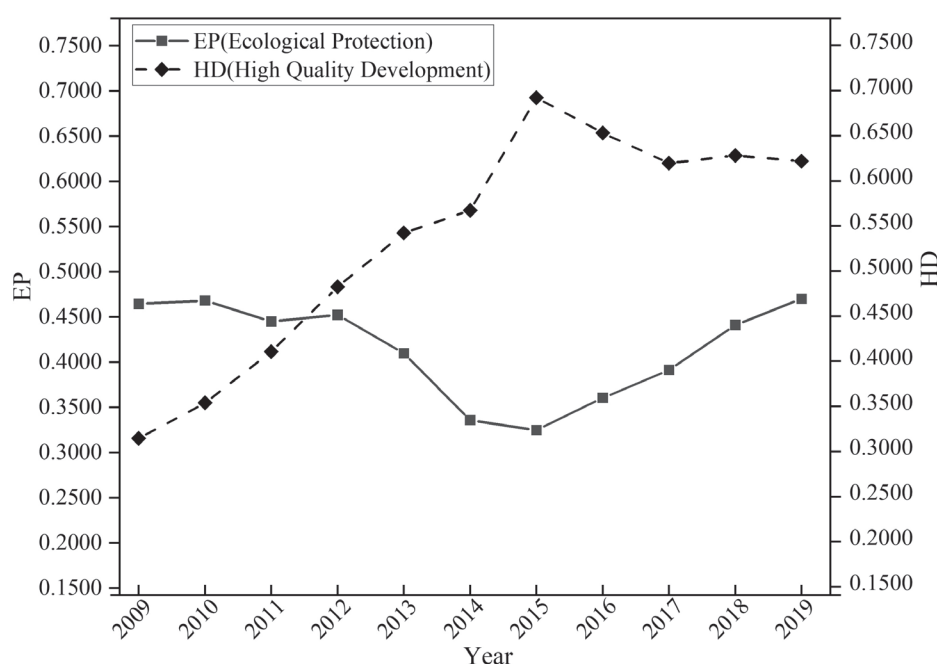


Fig. 1. Time-series changes in the level of ecological protection and high-quality development in Shandong Province.

Province during the "12th Five-Year Plan" period was 9.4%, which climbed to the third place in the country in 2015. On the other hand, the accelerated pace of industrial restructuring, the optimization of regional coordinated development pattern and the continuous expansion of innovation-driven benefits also The solid support has been provided. Third, during the 13th Five-Year Plan period, the high-quality development system has shown a trend of "first decreasing, then slowly increasing". The reason is that the transformation of old and new dynamics has reached a critical period, the regional economic growth rate has slowed down, and the problem of weakness of science and technology innovation to support high-quality development still needs to be solved. The continuous global optimization and regional coordinated development, the construction of green ecological economy and the continuous improvement of people's livelihood spending and a series of other measures have injected momentum for high-quality development.

Analysis of Temporal Changes in the Degree of Coupling and Coordination between Ecological Protection and High-Quality Development

According to the coupling and coordination model, the coupling and coordination index of ecological protection and high quality development in Shandong Province during the study period is calculated, and the results are shown in Table 3. The two systems of ecological protection and high-quality development have been in the grinding stage, and after 2017 the two systems tend to be coordinated. Combined with the analysis in Fig. 1, it is found that there is a phase change

characteristic for the change of their coordination degree, i.e., rapid growth (2009-2012), followed by small fluctuations (2013-2015), and then gradual improvement (2016-2019).

In the first phase, the level of ecological protection changed slightly while the quality development increased rapidly, and the coordinated development of the two accelerated over time and reached a synchronous development in 2011-2012. During this period, due to the impact of the global financial crisis and the pressure of "maintaining growth", the economy showed high growth since 2009, and the average annual growth rate of regional GDP reached more than 9.7%, higher than the value of any subsequent years. At the same time, Shandong Province is facing the "Eleventh Five-Year Plan" development period pollutant emission reduction rigid regulations, and the "Twelfth Five-Year Plan" to accelerate the transformation of economic development mode requirements. In the face of external pressures and economic development needs, Shandong Province gradually raised the status of ecological protection in economic and social development decisions, and promoted the optimization of economic growth through ecological protection, and promoted ecological protection and high-quality development in a concerted manner, so there was a short period of simultaneous development.

In the second phase, the coupling coordination degree fluctuated slightly, from 0.6865 in 2013 to 0.6606 in 2014, and then climbed to 0.6886 in 2015, because ecological protection is a systematic project, and the construction of ecological civilization and the transformation of the economic development mode need some time cost. Coupled with the limitation

of ecological and environmental resources carrying capacity, a virtuous resonance between ecological protection and high-quality development cannot be produced quickly, while the high-quality development system is elevated faster at this time. So it caused the fluctuation of coordination degree, appearing that ecological protection lagged behind high-quality development and the gap was obvious. between 2016 and 2019, ecological protection and high-quality development gradually developed from the abrasion to the coordination stage, rising from 0.6966 to 0.7352 in 2019, and the relative development degree also rose continuously from 0.5518 to 0.7558 in 2019. the reason is During the "Thirteenth Five-Year Plan" period, the transformation of new and old dynamic energy in Shandong Province has been effective, and the continuous increase in ecological and environmental management has strongly pushed the economic development mode and structural optimization, and the development of high-tech industries and resource-saving and recycling are prominent in supporting high-quality development, and the "two mountains". The "two mountains" theory is deeply implemented in the process of economic and social development. At this stage, ecological protection and high-quality development promote each other's benign development, and the level of coupling and coordination is steadily improved, gradually forming a coordinated economic and social development situation.

Identification of Obstacles to the Coordinated Development of Ecological Protection and High-Quality Development

(1) Subsystem level barrier factors. The obstacle degree of each subsystem level and individual indicators were measured by the obstacle degree model to identify the main obstacle factors affecting the coordinated development of ecological protection and high quality development in Shandong Province from 2009 to 2019, and the results are shown in Table 4. observing Table 4, it can be seen that the obstacle degree of 9 subsystems for the synergistic degree of ecological protection and high quality development in Shandong Province varied during the study period. In general, the three subsystems of ecological environment status, economic and social response and economic operation are the main obstacle factors, and their average values of obstacle degree are 36.27, 30.30 and 28.59 respectively during the observation period. three subsystems of social development pressure, innovation drive and green quality improvement gradually increase the obstacle degree, while the subsystems of environmental pollution pressure, social progress and life happiness show the development trend of gradually decreasing. This situation is roughly in line with the stage characteristics presented by the economic and social development process. In the initial stage, the damage to the natural ecosystem caused by economic development

Table 3. Time series change of coupling and coordination between ecological protection and high-quality development in Shandong Province.

Classification	Year										
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
D	0.6182	0.6380	0.6539	0.6835	0.6865	0.6606	0.6886	0.6966	0.7017	0.7256	0.7352
R	1.4756	1.3229	1.0823	0.9369	0.7554	0.5918	0.4689	0.5518	0.6315	0.7020	0.7558
Coupling coordination phase	Break-in	Break-in	Break-in	Break-in	Break-in	Break-in	Break-in	Break-in	Coordination	Coordination	Coordination
	VI	VI	V	V	IV	IV	IV	IV	VII	VII	VII

Table 4. Barrier degree and ranking of each subsystem layer.

Classification		Year										
		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
E1	Obstacle degree	35.65	33.59	28.11	24.48	52.90	39.04	36.43	36.93	37.37	34.52	39.98
	Ranking	2	2	4	5	1	1	2	1	1	3	2
E2	Obstacle degree	0.69	1.97	2.36	3.83	13.30	16.81	16.97	18.91	21.33	24.75	27.50
	Ranking	9	9	9	9	6	7	6	6	5	5	5
E3	Obstacle degree	22.16	22.44	30.64	31.43	29.88	27.04	25.10	15.20	9.33	6.11	0.00
	Ranking	5	5	2	2	2	4	4	8	9	9	9
E4	Obstacle degree	41.50	42.00	38.89	40.26	3.92	17.11	21.51	28.96	31.97	34.61	32.53
	Ranking	1	1	1	1	9	6	5	3	3	2	3
H1	Obstacle degree	20.30	20.51	21.21	25.97	27.36	30.08	37.09	32.35	27.59	26.38	45.65
	Ranking	6	6	6	4	3	2	1	2	4	4	1
H2	Obstacle degree	15.13	14.39	14.68	13.24	13.07	12.37	9.67	7.82	10.49	14.07	16.34
	Ranking	7	7	7	7	7	8	9	9	8	6	6
H3	Obstacle degree	13.20	11.07	10.93	10.54	9.16	5.69	12.36	22.93	37.18	39.37	30.84
	Ranking	8	8	8	8	8	9	8	4	2	1	4
H4	Obstacle degree	28.21	29.81	29.61	27.26	27.33	28.71	13.69	15.53	10.94	12.40	4.30
	Ranking	3	3	3	3	4	3	7	7	7	7	7
H5	Obstacle degree	23.16	24.22	23.57	22.99	23.08	23.15	27.19	21.38	13.81	7.79	2.87
	Ranking	4	4	5	6	5	5	3	5	6	8	8

is still shallow, and the ecological environment is in a good state to support economic and social development. With the rapid advancement of industrialization and urbanization, the economy has entered a stage of rapid development, and the ideas of "pollution before treatment" and "GDP-only theory" have gradually alienated the idea of development. Large-scale environmental pollution, serious resource consumption has become the norm for development. Transformation of structural adjustment and implementation of the strictest environmental management system, green development and scientific and technological innovation to drive ecological protection and high-quality development of synergistic development has become an inevitable choice.

(2) Indicator level barrier factors. The calculation results of the barrier degree of individual indicators are shown in Table 5. As can be seen from Table 5, the top 3 of the barrier factors ranked in the top 5 from 2009 to 2019 are mainly concentrated in the ecological and environmental state, environmental pollution and economic and social response subsystems. Among them, the proportion of wetland area (X2) has been in the first place for 7 consecutive years since 2013, the fertilizer application (X13) decreases from the 2nd to the 3rd place, and the new flood removal area (X17) appears in the 1st, 2nd and 3rd places alternately. The 4th

and 5th indicators in the ranking of the top five obstacle factors mainly come from the two subsystems of social development pressure and economic operation, among which regional development intensity (X9) and the proportion of retail sales of social consumer goods to GDP show obvious roles with four and three consecutive occurrences, respectively. This also indicates that the ecological degradation and environmental pollution problems brought about by economic and social development, and whether effective measures can be taken for ecological restoration and protection in the face of fragile ecological environment, and whether the economic structure can be effectively adjusted to establish new economic growth poles, are particularly important for achieving the virtuous resonance between ecological protection and high-quality development to promote the coordinated development of the two. In addition, the comprehensive utilization rate of general industrial solid waste and health insurance coverage rate of 2 single indicators repeatedly, also shows that the process of high-quality development to accelerate resource conservation, recycling, and expand the number of people enjoying social security so that more citizens share the fruits of development is also not negligible part.

Table 5. Calculation results and ranking of barrier degree of individual index layer.

Year	Ranking of indicators									
	1		2		3		4		5	
	Indicators	Obstacle degree	Indicators	Obstacle degree	Indicators	Obstacle degree	Indicators	Obstacle degree	Indicators	Obstacle degree
2009	X17	18.60	X13	14.86	X1	14.02	X34	11.89	X14	10.19
2010	X17	17.25	X13	15.57	X1	14.44	X34	12.93	X14	10.36
2011	X17	17.82	X34	15.54	X13	14.25	X1	13.50	X22	11.41
2012	X34	19.27	X17	18.16	X13	15.34	X1	14.06	X22	12.16
2013	X2	22.90	X34	21.56	X13	14.87	X1	14.26	X22	13.04
2014	X2	21.95	X34	21.66	X17	15.04	X13	13.41	X40	13.38
2015	X2	21.50	X40	15.32	X17	15.06	X13	12.31	X9	10.02
2016	X2	23.48	X17	19.34	X31	16.80	X36	12.48	X13	12.05
2017	X2	24.91	X31	21.98	X17	19.06	X32	13.55	X9	12.63
2018	X2	29.11	X31	23.46	X17	22.11	X9	15.83	X32	15.18
2019	X2	28.47	X31	22.71	X17	18.49	X9	15.48	X20	14.16

Prediction of Coupled Coordination between Ecological Protection and High-Quality Development

The original values of the coupling coordination degree of ecological protection and high quality development in Shandong Province from 2009 to 2019 were used to achieve the GM (1,1) gray prediction with the help of DPS7.05 statistical analysis software, and the prediction results are shown in Table 6. The C and P values of the four residual series analysis are also in the "good" and "very good" states. The C and P values of the four residual series analyses are also in the "good" and "very good" states. This indicates that the current prediction model has high accuracy and is suitable for predicting the coupling coordination between ecological protection and high-quality development. In addition, to test the accuracy of the prediction model, a double test was conducted by comparing the fitting trends of the original and predicted values, and the test results are shown in Fig. 2. The results are shown in Fig. 2. It can be seen from Fig. 2 that the original and predicted values of the coupled coordination degree achieve a good fit and a small error range, with an average error of

0.82% during the study period, so it can be considered that the accuracy of this coupled coordination degree prediction model of ecological protection and high-quality development is about 99%.

According to Table 6, the coordination degree of ecological protection and high quality development in Shandong Province has been increasing during the prediction period (2020-2023), from 0.7394 in 2020 to 0.7699 in 2023, and the overall coordination is in the state of coordination but the rate of improvement is slow, with an average annual increase of 0.0076. Further, combined with the prediction results of relative development degree, it is found that ecological protection still lags behind High-quality development, and there is a decreasing feature year by year. Therefore, for future development we should deeply understand the connotation of ecological protection and high quality development strategy in Yellow River Basin, and grasp the law of mutual promotion between ecological protection and high quality development. Increase the ecological protection, improve the ecological fragility of the problem to find a solution to high-quality development, and then achieve comprehensive, coordinated and sustainable economic and social development.

Table 6. Forecast of coupled coordination between ecological protection and high-quality development.

Year	Predicted value	Model Evaluation	Number of residual analysis	C	P
2020	0.7394	C = 0.3310 P = 1.0000	1	0.2991	0.9000
2021	0.7494		2	0.3329	1.0000
2022	0.7596		3	0.3678	1.0000
2023	0.7699		4	0.4382	1.0000

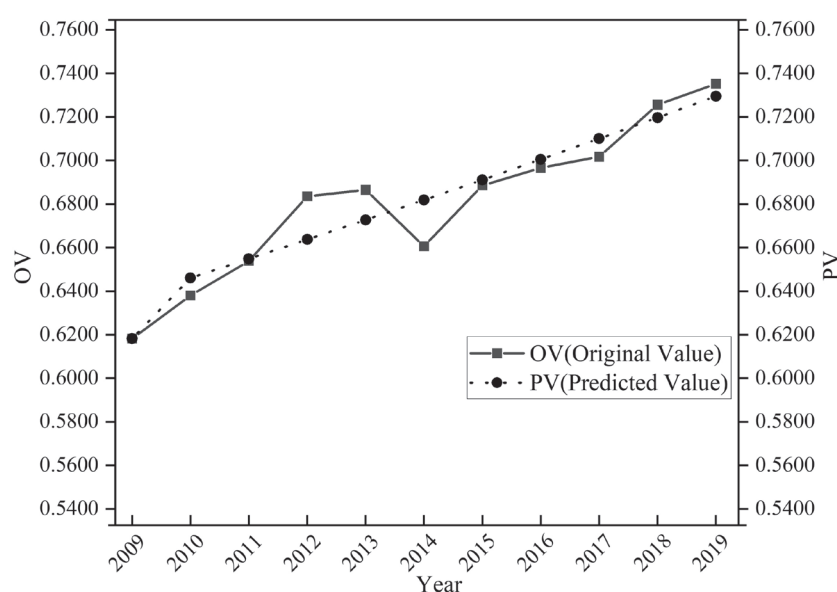


Fig. 2. Trend of fit of original and predicted values of coupling coordination.

Discussion

Deeply understand the interrelationship between ecological protection and high-quality development, and strive to achieve the coordination and resonance of both.

The major strategy of ecological protection and high-quality development of the Yellow River Basin has pointed out the direction for the Yellow River Basin, and also made development guidance for the economic and social development of the provinces along the Yellow River. Shandong Province, as a strong economic and cultural province in the lower reaches of the Yellow River, has a relatively excellent economic ability to support high-quality development, but ecological fragility, environmental pollution and water shortage are still the main constraints at present. It should promote high-quality development with ecological protection and boost ecological protection with high-quality development on the basis of deep understanding of strategic connotation. To this end, we need to speed up top-level design and planning, formulate development plans in line with the actual situation in the province; improve the construction of institutional mechanisms for coordinated development, establish a leading group for ecological protection and high-quality development, strengthen the integration among departments, personnel, elements and funds, and promote ecological protection and high-quality development toward a highly coordinated state with a mechanism of multiple subjects, multiple departments and multiple policy synergies.

Continuously increase ecological protection to create a new growth pole for high-quality development.

Ecological environmental protection and management is a complex and systematic project, the effect cannot be achieved overnight and requires

persistent cost investment. The problems of resource depletion, environmental pollution, and ecological degradation that accompany the sloppy economic development are very likely to cause irreversible damage to the natural ecosystem. Therefore, it is necessary to protect ecology throughout the whole process of economic and social development, and continuously increase the investment in ecological protection. Based on the actual situation in the province, we will increase the restoration and treatment of the wetland ecosystem in the Yellow River Delta and accelerate the construction of a green ecological corridor in the lower reaches of the Yellow River; strictly implement the environmental management system and establish a multi-category, vertical and horizontal ecological compensation system; rely on the advantages of economic development, establish a green ecological industrial system and achieve "going out" with the help of "digital empowerment"; and continue to "We will continue to speed up the transformation of old and new dynamics, optimize the structure of various industries, increase investment in human and capital resources for science and technology innovation, and enhance the status of high-tech new industries in economic growth. Leveraging its relative advantages in location, science and technology and industry, it will achieve coordinated ecological protection and high-quality development, and play an exemplary leading role for the rest of the Yellow River Basin provinces.

Conclusions

Based on the coupled coordination model and the barrier degree model, we analyze the panel data of economic and social development in Shandong Province from 2009 to 2019, identify the barrier factors affecting

the coupled coordination degree, and make predictions with the help of GM (1, 1) model on the basis of the analysis to obtain the following conclusions.

(1) The overall trend of ecological protection and high-quality development in Shandong Province is increasing, and the development status evolves from "lagging in high-quality development" to "lagging in ecological protection". Among them, the level of ecological protection has gone through three stages of change, i.e. "first zigzag changes, then a significant decline, and then a steady increase". The high quality development level, on the other hand, has a "high to low" speed change. The development status between the two is more in line with the stage characteristics of economic and social development.

(2) The coupling and coordination between ecological protection and high quality development in Shandong Province has been increasing during 2009-2019, and the development has been gradually moving from the state of "friction" to the state of "coordination" with 2017 as the dividing line. The speed shows the characteristics of "rapid growth - small fluctuation - steady improvement", and the development characteristics have gone through four stages: low degree of friction, short high degree of friction, low degree of friction and low degree of coordination.

(3) From 2009 to 2019, the barrier factors affecting the degree of coupling and coordination of ecological protection and high-quality development in Shandong Province varied. The subsystem level is mainly distributed in 3 aspects: ecological and environmental status, economic and social response, and economic operation. Indicators such as the proportion of wetland area, fertilizer application, new flood removal area and the ecological and environmental security and pollution problems represented in the indicator level deserve attention.

(4) GM (1, 1) gray prediction model shows that the coordination degree of ecological protection and high-quality development in Shandong Province will continue to improve in the next 4 years, gradually increasing from 0.7394 to 0.7699. However, the rate of improvement is slow, and overall it is still in the low coordination (VII) type where ecological protection lags behind high-quality development, and has not yet achieved the situation of crossing over to VIII type.

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Conflict of Interest

The authors declare no conflict of interest.

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