Journal of Economics and Management Sciences; Vol. 8, No. 3; 2025
ISSN 2576-3008 E-ISSN 2576-3016
https://doi.org/10.30560/jems.v8n3p58

The Necessary Logic of Multiple Cooperative Governance of Ecological Environment

Xiao Li[1] & Xiaoxuan Liu[1]

[1] School of Economics and Management, Shaanxi University of Science and Technology, China

Correspondence: Xiaoxuan Liu, School of Economics and Management, Shaanxi University of Science and Technology, Xi'an, Shaanxi 710021, China.

Received: May 12, 2025; Accepted: May 29, 2025; Published: May 30, 2025

Abstract

For regional ecological environment governance, demonstrating the rationality of its intergovernmental multi-collaboration is crucial for strengthening cross-border cooperation, enhancing holistic ecological security, and promoting high-quality integrated development. Environmental pollution, green total factor productivity, resident health, etc, of 30 provincial-level regions from 2001 to 2020 are explained variables from the perspectives of local government, enterprises, and residents. Spatial econometric models are applied to test the spatial correlation between diverse groups in different regions and ecological environment governance, aiming to obtain empirical evidence for the necessity of diverse groups' participation in intergovernmental ecological environment governance. We primarily find that the explained variables reflecting the core interests of diverse groups are spatially correlated, and ecological environment governance has significant spatial spillover effects on them, reducing surrounding environmental pollution by 3.2542, increasing green total factor productivity of enterprises by 8.5120, and improving resident health by 0.8267. Furthermore, by comparing the regression results under different spatial weight matrices, we provide suggestions for intergovernmental coordination, including implementing a particular consciousness of responsibility for everyone's participation, enhancing the identification and management of externalities in ecological environment governance, and enriching and optimizing tools for the participation of diverse stakeholders.

Keywords: regional ecological environment governance, collaborative legitimacy, diverse groups, spatial econometric model

1. Introduction

Ecological environment resources are natural elements produced jointly by ecological and social systems, providing direct or indirect benefits for human well-being through material supply, environmental management, and cultural and supporting services. Distinct from traditional material and cultural resources, the purpose of their construction is to "satisfy the need for a beautiful ecological environment", "alleviate the imbalance and inadequacy of development", and "safeguard human life and health", which plays a pivotal role in the more extensive interests of national economic development and socialist modernization drive. Currently, China's ecological environment governance can be broadly divided into means targeting geographical areas with clearly defined functions, such as single ecological elements (forests and grasslands) or watersheds, and means targeting complex regions with a primary function of providing ecological products and services, such as key ecological functional zones and national parks. As many researchers have concluded that "a single entity cannot effectively solve ecological environment governance issues," the former approach mentioned above can be calculated based on the ecological service value, considering the identity of rights and obligations, and undertaking functional losses associated with regulating the allocation of ecological environment resources through diverse entities. Due to its specific spatial scale [Note 1], the latter approach exhibits significant diversity, aggregation, and integrity of ecological environment resources. Moreover, related institutions confirm that some groups must contribute labor or bear costs for ecological products or services in a different area. These complex regions have proved difficult in the method of the "spillover" in ecological benefits. However, this is legitimate evidence for guiding or compelling diverse entities from different areas to participate in regional ecological environment governance, which is related to determining whether diverse collaborative governance can acquire recognition and be implemented. [1]

According to China's Major Function-oriented Zone Planning, more than 53% of the national territory requires ecological environment governance, such as key ecological functional zones. In some provinces like Sichuan, ecological functional zones account for more than 60% of the provincial area. This status quo proves the rationality of intergovernmental collaboration among local governments, enterprises, residents, etc. This cooperation is essential in strengthening cross-regional ecological environment governance, enhancing holistic ecological security, and promoting high-quality integrated development. In line with the trends above, this paper intends to use spatial econometric analysis of panel data from 30 provincial-level regions (excluding Tibet) from 2001 to 2020 as an example to explore whether ecological environment governance exhibits spatial spillover. It aims to provide feasible evidence that local governments, enterprises, residents, and other diverse entities can be utilized spatially in the governance of ecological environments in different areas on the premise of reducing the complexity of the methodology.

2. Literature Review

For the protection and governance of the ecological environment, dated from the 1980s, some countries have proposed that "collaborative cooperation" would be the mainstay of the future development of ecological environment management systems. This approach advocates the role of the "invisible hand", emphasizing that governments should entitle entities such as enterprises and the public to jointly address ecological environment issues through self-management and participation in governance. [2] Some developed countries have already implemented collaboration in fields such as the prevention and control of water pollution in watersheds, air pollution, ecosystem restoration, regional environmental planning, and the protection of land use and open spaces. Traditional environmental governance methods such as command-and-control regulations, centralized planning, and technocratic management are gradually being replaced. In parallel, China's ecological environment protection and governance policies have also shifted from "centralized control" to "multi-departmental cooperation and public participation." A series of policies of China, such as the Action Plan for Establishing a Market-based and Diversified Mechanism for Ecological Protection Compensation and the Guidance on Building a Modern Environmental Governance System, demonstrate the need for decentralization to enhance the production capacity of the ecological environment, diverse stakeholders' involvement into market regulation and utilization of the decisive role of the market in allocating ecological environment resources. In practice, some initiatives, including carbon trading, water rights trading, pollution discharge rights trading, cross-ecological compensation in the Xin'an River Basin, coordination in the South-to-North Water Diversion Project, joint prevention and control of air pollution in the Beijing-Tianjin-Hebei region, and multi-assistance in key ecological functional areas all outline a blueprint for the governance of the ecological environment—co-construction, sharing, and multi-dimensional collaboration.

Different types of ecological environment resources involve various collaborative stakeholders. In some countries, the main collaborative patterns are listed below:

1. Intergovernmental cooperation led by the central government, as exemplified in managing air pollution and water environments. Significant cross-region spillover effects exist because of the mobility characteristics of these two types. The central government and local governments inevitably encounter coordination issues. The former must grant sufficient authority, while the latter must cooperate and share rights. [3][4][5]

2. Multi-governance under government coordination, including enterprises and social organizations. Research refers to watersheds, forests, climate change, green industry chains of fisheries, ecosystem services, urban green transition, etc. Government actions in collaborative governance can be influenced by various potential transaction costs and the existing management structures of resources. Involving other entities and using market-based approaches can better promote cooperation. [6]

3. Involvement of community residents. Ecological and environmental issues are considered common problems for humans. The recommended approach in recent research is to devolve the rights and responsibilities of ecological resource management to local communities. [7] [8]

4. Cross-border cooperation under international legal frameworks or regional agreements. Due to asymmetric barriers such as domestic and international pressures, national capacities and economic interests, the effectiveness of governance regulated by higher-level ecological environment treaties is limited. [9]

Similarly, Chinese scholars also believe that sustainable development of the ecological environment requires a combination of "top-down" and "bottom-up" approaches, which utilize the power of the government as well as other social forces. [10] [11]The definition of entities in co-construction and sharing of the ecological environment are mainly summarized below:

1.Inter-governmental prevention and control of air pollution. For areas where air quality is relatively worse or critical, such as the Beijing-Tianjin-Hebei region, the Yangtze River Delta region, and the Fen-Wei Plain, local governments are required to cooperate closely and establish collaborative frameworks. [12]

2.Ecological compensation and collaborative governance in cross-regional watersheds, led by the central government, involving upstream and downstream provinces as well as provinces across watersheds, is widely implemented in areas such as the Xin'an River, Dongjiang River, Luanhe River, and Taihu Lake. [13] [14]

3.Multi-entities in the protection and restoration of the ecological environment. In this pattern, the government no longer holds a dominant position as a participant. Its functions mainly focus on reasonable regulation, stimulation and inducement, as well as standardization and coordination. Protection and restoration costs are dispatched to the market, non-governmental organizations, and citizens. This measure covers multiple fields, including water environments, forests, grasslands, watershed compensation, etc. [15] [16]

Both practices and research acknowledge that due to objective factors like "free-riding" and the "tragedy of the commons", the current administrative system, where local authorities are responsible for ecological environments and the central government compensates, along with fragmented governance, will malfunction. This system cannot effectively incentivize conservation actions on the ecological environment or suppress environmentally hazardous behaviors. Therefore, ecological users need to be involved in co-construction and sharing. However, existing research has focused chiefly on emphasizing the importance of multiple stakeholders using theories related to externalities, stakeholders, and game theory without providing clear evidence of the relationship of "governance-participation" between ecological conservation areas and other entities from different regions. It is challenging to prove that one region's ecological protection will provide what types of ecological service functions to which areas, which leaves problems about the legitimacy of multi-participation in regional ecological environment governance.

3. Spatial Interest-Related Analysis

To provide ecological products and services, certain regions face developmental constraints and incur financial and material costs. In theory, interest-related groups should assist these regions in alleviating conservation pressures through financial or behavioral compensation. The key lies in verifying their correlations and identifying the "interests" involved. This is crucial for motivating the consciousness of distant groups not geographically involved in ecological conservation. Generally, society consists of government, enterprises or profit-oriented organizations, and non-governmental or non-profit organizations, each playing different roles in promoting social development jointly. Specifically in ecological environment governance, these three groups mainly refer to local governments, enterprises, and residents. Each entity needs to play a role based on its characteristics to promote normalization, order, and health in developing ecological environmental resources, protect the environment, and maintain ecological balance. It is essential to stimulate the proactiveness of multiple stakeholders in collaborative participation so that the superimposed effects of cross-regional ecological conservation can be achieved through integrating resources, functional complementarity, and interest sharing among local governments, enterprises, and residents from different areas. This not only requires logical validation in theory, values, and practice but also necessitates the recognition of interest-related economic evidence.

First, for local governments in different regions, according to their heterogeneous functions in territorial space, certain regions are assigned the primary responsibility for ecological environment governance, while others focus on economic development. The former nurtures the ecology and balances high-quality development, and the latter enjoys the ecological dividends of the former and lacks the compensatory opportunities available to the former. As representatives of regional administration, local governments undertaking ecological conservation governance face no concerns about the self-consumption of environmental resources, and the "benefits" they receive are changes in the amount of pollution. Second, for enterprises in different regions, as the core of economic development, their participation in governance is based on profit motives and ethical considerations. The profit motives primarily refer to the modernization that requires enterprises to internalize environmental pollution and its governance costs as production costs. This results in the inevitable elimination of outdated production capacity, equipment, and processes. Meanwhile, green constraints in the market constitute an endogenous incentive for industrial transition and structural upgrading. On the other hand, the ethical considerations mainly indicate that enterprises, as consumers and destroyers of ecological environment resources, should have a moral obligation to manage the environmental pollution they cause actively. In comparison, the speculative behavior of enterprises in multi-participation is mainly driven by profit motives. Therefore, the spatial impact of ecological environment governance on enterprises in different regions revolves around loss avoidance, cost reduction, and profit increase, where industrial green total factor productivity represents the spatial variation of enterprises. [17][18]Third, distant residents in different regions primarily suffer the consequences of environmental pollution and benefit from a beautiful ecological environment in the industrial era. Their intrinsic motivation to participate in ecological environment governance is not merely a response to individual emotions or human fate but an insight into their benefits. This insight is most directly related to concerns about survival risks, and the essential "benefit" they seek is fundamentally about health. In summary, potential spatially related data evidence for local governments, enterprises, and residents in different regions in ecological environment governance can be analyzed in three aspects: changes in amounts of pollution, green total factor productivity, and health(see Figure 1).

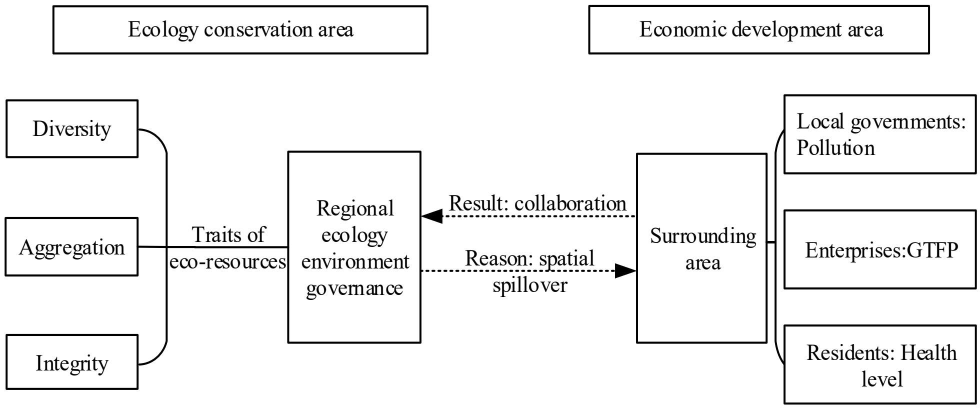

Figure 1. Analysis of Spatial Interests

4.4 Methodology

4.1 4.1 Selection of Differential Indicators

Characterization parameters of ecological environment governance. Since ecological environment governance is procedural, previous studies typically elaborated its characteristics from two perspectives: inputs and outputs. For the input, the strength of governance can be evaluated through policy-related indicators, such as the number of environmental regulation policies issued and the number of environmental regulation policy administrators. [19]The governance investments can be estimated by financial indicators, such as investments in environmental pollution control and operating expenses for environmental pollution control facilities. [20]For the output, the performance of governance can be assessed from both positive and negative aspects, which involve changes in environmental pollution emissions (e.g., carbon dioxide emissions, sulfur dioxide emissions, wastewater discharge, air emissions, solid waste discharge) or changes in the stock of ecological environment resources (e.g., forest coverage, per capita water resources). [21] [22]Additionally, some studies have used per capita income and total energy consumption as substitute variables to measure ecological environment governance. Since ecological environment governance is a long-term project and its performance is influenced by external factors such as geographic features and technological maturity, a region's efforts in ecological environment protection may not be adequately evaluated from the perspective of output. Therefore, indicators from the input perspective were chosen in this study. Considering that the effectiveness of environmental regulation policies is closely related to the willingness of local governments, this study uses investments in pollution treatment to represent the strength of ecological environment governance in a region. On the other hand, financial negotiations and complementarity are also a primary method for current multi-participation. Therefore, using investments in pollution treatment as one of the variables is justified.

Indicators of local governments. Based on the analysis above, the potential benefits for local governments in different regions from ecological environment governance involve not focusing excessively on pollution issues, namely macro-level pollution reduction. When measuring environmental pollution, excluding uncontrollable factors, pollutants generated by industrial production are the main contributors. These are typically measured by the Environmental Quality Index, Environmental Composite Index, Environmental Sustainability Index, and Environmental Efficiency Index. Since a single pollution indicator cannot characterize environmental pollution comprehensively, and considering data continuity, timeliness, and availability, this study utilizes the entropy weight method to calculate the Environmental Pollution Composite Index for each province or region based on the major indicators related to the "three wastes": industrial wastewater discharge, industrial sulfur dioxide emissions, and general industrial solid waste generation. This approach provides a comprehensive assessment of environmental pollution. Regarding control variables, economic development level, industrial structure, urbanization rate, level of opening-up, level of technological progress, and population density are selected to test the consistency of regression results. Additionally, due to the Kuznets curve relationship between the environment and the economy, quadratic terms for economic development level and ecological environment governance are also included in the control variables. [23 [24]

Indicators of Enterprises. Based on the analysis above, the relationship between enterprises and the ecological environment primarily is that ecological environment governance might affect environmental protection investments by enterprises in different regions and indirectly impact green output. Therefore, this study selects the Green Total Factor Productivity (TFP) as a spatial interest-related variable for enterprises to analyze the spatial correlation between enterprises and ecological environment governance. The Green TFP of enterprises is calculated by the non-directional, variable returns to scale super-efficiency Data Envelopment Analysis (DEA) model EBM combined with the Global Malmquist-Luenberger (GML) index. [25]Among the calculation, input indicators include capital, labor, and energy input, while output indicators include expected and non-expected output. [26]Control variables primarily are economic development level, industrial structure, urbanization rate, opening-up level, and technological progress. Similarly, considering the potential non-linear relationship between governance investment and Green TF implies that moderate governance intensity can stimulate technological innovation by enterprises. However, excessive strictness may lead to declining profits and hinder green innovation. This study adds an ecological environment governance squared term into control variables.

Indicators of residents. Based on the analysis above, ecological environment governance's positive impact on residents' health in different regions can encourage their participation. The concept of health is complex, commonly measured by indicators such as population mortality rate, neonatal mortality rate, infant mortality rate, under-five mortality rate, maternal mortality rate, and per capita life expectancy. [27] It is not suitable to measure the impact of the ecological environment on resident health using mortality rates because the effects are relatively slow, and multiple factors typically contribute to mortality. Moreover, Per capita life expectancy is unsuitable for panel data analysis due to its lack of continuity. Considering the multifaceted impact of the ecological environment on resident health and data availability, this study selects the number of outpatients as a negatively measured variable for the level of health. This indicator characterizes the comprehensive external impact of the ecological environment on health from the perspective of passive medical diagnosis. [28]Other control variables are mainly based on Grossman's health production function. They are selected from economic, medical, educational, and social aspects, which include per capita GDP, the proportion of the tertiary sector, the share of medical and health expenditure in fiscal expenditure, the number of physicians per ten thousand people, per capita years of education, and population density.The statistical descriptions of each variable are shown in the following table(see Table 1).

Table 1. Index system and descriptive statistics

Types	Classification	Indexes	Denotes	Min	Max	Average	Standard deviation	Stakeholders
Core explanatory variables	Eco-environment governance	investment in industrial pollution governance/GDP	ZL	0.0009	0.9920	0.1500	0.1324	government/enterprise/resident
Explained variables	Environment pollution	industrial wastewater discharge, industrial sulfur dioxide emission, general industrial solid waste (based on the entropy weight method)	Y^1	0.0100	0.7794	0.2369	0.1508	government
	GTFP	input: net value of industrial fixed assets, total industrial employment, total industrial energy consumption output: industrial value-added, entroy weight of industral 'three wastes' (based on EBM-GML model)	Y^2	0.7887	10.3308	1.9465	1.1256	enterprise
	Health	number of outpatients	Y^3	15.2518	19.8103	17.8465	0.8626	resident
	Economy	lg(per capita GDP)	JJ	7.9707	12.0130	10.2343	0.8364	government/ente

	development							rprise/resident
Control variables	Industrial structure	Added value of the tertiary industry/ *GDP*	*CY*	27.4113	83.8682	42.7866	9.3525	government/enterprise/resident
	Urbanization rate	Urban population/total population	*CZ*	13.885	89.6066	51.7141	15.0352	government/resident
	Openning-up level	Total trade volume/ *GDP*	*DW*	0.7575	172.277	30.2340	36.7294	government/resident
	Techonology progress	Technology market turnover/ *GDP*	*JS*	0.0053	17.4951	1.1365	2.2683	government/enterprise
	Population density	Total population/total area of the region	*RK*	4.0254	8.7495	7.6132	0.7026	government/resident
	Investment in public health	the share of medical and health expenditure in fiscal expenditure	*WS*	2.1168	9.6467	5.3818	1.8823	resident
	Medical level	the number of physicians per ten thousand people	*YL*	2.2450	3.8960	2.9775	0.2997	resident
	Education level	per capita years of education	*JY*	6.0405	12.782	8.7404	1.0667	resident

Due to the publication of health-related data starting from 2003, the research period of residents is from 2002 to 2020. Data from other stakeholders are ranges from 2001 to 2020.

4.2 Spatial Econometric Model

To investigate whether local governments, enterprises, and residents in different regions are influenced by the ecological environment governance of conservation areas, i.e., whether there is empirical evidence of spatial spillover in ecological environment governance and whether there is a spatial correlation between multiple entities and the ecological environment, it is necessary to establish models using spatial geographical factors. Based on spatial econometric theory, the general spatial nested models from the perspectives of local governments, enterprises, and residents are established as follows [29]:

Local governments:

$$\begin{aligned} Y_{it}^1 &= \alpha^1 + \rho^1 W Y_{it}^1 + \beta_1^1 ZL_{it} + \beta_2^1 WZL_{it} + \theta_1^1 X_{it}^1 + \theta_2^1 WX_{it}^1 + \mu_{it}^1 \\ \mu_{it}^1 &= \lambda^1 W \mu_{it}^1 + \varepsilon_{it}^1 \quad \varepsilon^1 \sim N(0,\ \sigma^2 I_n) \end{aligned} \tag{1}$$

Enterprises:

$$\begin{aligned} Y_{it}^2 &= \alpha^2 + \rho^2 W Y_{it}^2 + \beta_1^2 ZL_{it} + \beta_2^2 WZL_{it} + \theta_1^2 X_{it}^2 + \theta_2^2 WX_{it}^2 + \mu_{it}^2 \\ \mu_{it}^2 &= \lambda^2 W \mu_{it}^2 + \varepsilon_{it}^2 \quad \varepsilon^2 \sim N(0,\ \sigma^2 I_n) \end{aligned} \tag{2}$$

Residents:

$$\begin{aligned} Y_{it}^3 &= \alpha^3 + \rho^3 W Y_{it}^3 + \beta_1^3 ZL_{it} + \beta_2^3 WZL_{it} + \theta_1^3 X_{it}^3 + \theta_2^3 WX_{it}^3 + \mu_{it}^3 \\ \mu_{it}^3 &= \lambda^3 W \mu_{it}^3 + \varepsilon_{it}^3 \quad \varepsilon^3 \sim N(0,\ \sigma^2 I_n) \end{aligned} \tag{3}$$

Where, Y^1, Y^2, Y^3 are the dependent variables for local governments, enterprises, and residents, respectively. ZL is the core explanatory variable of ecological environment governance. X^1, X^2, X^3 are the control variables for each perspective. ρ^1, ρ^2, ρ^3 are the spatial autocorrelation coefficients. β, θ etc., are the regression coefficients of explanatory variables for the local or neighboring areas. $\mu_{it}^1, \mu_{it}^2, \mu_{it}^3$ are error terms, and $\varepsilon_{it}^1, \varepsilon_{it}^2, \varepsilon_{it}^3$ are random disturbance terms. W is the spatial weight matrix. Spatial econometric models can be transformed into Spatial Error Models (SEM), Spatial Autoregressive Models (SAR), and Spatial Durbin Models (SDM) based on the variation of estimating parameters in each spatial lag term. The most suitable model for regression analysis can be determined through empirical testing.

4.3 Construction of Spatial Weight Matrices

The spatial connection between multiple entities in different regions and ecological environment governance is influenced by geographical distance, on the one hand. Various products and services generated by ecological environment resources have geographical radiation or diffusion effects, which deduces that entities closer to these resources may experience more intensive impacts. On the other hand, this connection may also be related to the level of economic development. Regions with similar levels of economic development tend to imitate and learn from each other, leading to more similar ecological environments, and various entities within them may be more affected. Based on these factors, this study constructs two spatial weight matrices, including the traditional symmetric geographical distance weight matrix $W1$ and a new asymmetric geographical-economic weight matrix $W2$, to comprehensively reflect the spatial spillover effects among variables and enhance the robustness of the empirical results:

1.Geographical Distance Weight Matrix $W1$: The geographical distance i between region j and region d_{ij} is calculated using latitude and longitude. If $i \neq j$, the matrix element is $w1_{ij} = \frac{1}{d_{ij}}$, and if $i = j$, it is $w1_{ij} = 0$. The closer the geographical distance between different spatial units, the larger the matrix element, reflecting more substantial spatial effects between the two regions.

2.Geographical-Economic Weight Matrix $W2$: There are limitations in constructing a weight matrix only using geographical or economic distance. The relationships between different regions from the perspective of economic and geographical connections are also analyzed. However, spatial economic connections between different regions are often asymmetric. Developed regions typically influence their less developed counterparts more than vice versa. In other words, the positive impact of developed regions on less developed regions is more significant than the reverse impact. To address the limitations of traditional symmetric geographical-economic distance weight matrices, elements of $W2$ are $w2_{ij} = \frac{1 \cdot perGDP_j}{d_{ij} \cdot perGDP_i}$, $i \neq j$, otherwise $w2_{ij} = 0$.

5. Empirical Results and Analysis

5.1 Spatial Correlation Testing and Model Selection

Spatial correlation testing is one of the critical prerequisites for spatial econometric analysis. Since traditional testing methods like Moran's I, Geary's c, LMError, LMLag, or R-LMError, R-LMLag are initially designed for cross-sectional data, the spatial weight matrices are expanded into block matrices. Then, these testing methods can be extended to panel data models(see Table 2). First, Moran's I indexes of the dependent variables Y^1, Y^2, Y^3, and the core explanatory variable ZL of local governments, enterprises, and residents are all significantly greater than 0 at the 1% significance level, and Geary's c indexes of them are all significantly less than 1 at the 1% significance level. [Note 2]This indicates that all variables exhibit significant spatial correlations, meaning their spatial distributions are not independently changing but have spatial spillover or diffusion effects between regions. Second, the significance of LMError, LMLag, and their robust variables also confirms the feasibility of spatial econometric analysis.

Table 2. Results of spatial correlation test and model selection

Geographical Distance Weight Matrix $W1$				
Indexes	ZL	Y^1	Y^2	Y^3
Moran's I	0.184***(14.094)	0.153***(11.636)	0.450***(34.259)	0.243***(18.019)
Geary's c	0.819***(-9.282)	0.869***(-8.914)	0.569***(-23.395)	0.740***(-17.373)
		local governments	enterprises	residents

LM test	LMError	44.450***	8.815***	0.769
	R-LMError	3.173*	0.629	9.400***
	LMLag	48.005***	10.966***	11.329***
	R-LMLag	6.727***	2.780*	19.960***
LR test	LR-SAR	70.94***	24.97***	81.02***
	LR-SEM	68.89***	25.30***	91.39***
Hausman		-330.21	58.01***	301.4***
Geographical-Economic Weight Matrix $W2$				
Indexes	ZL	Y^1	Y^2	Y^3
Moran's I	0.168***(11.928)	0.125***(8.841)	0.496***(35.035)	0.240***(16.480)
Geary's c	0.773***(-5.397)	0.940***(-2.629)	0.652***(-9.092)	0.750***(-11.052)
		local governments	enterprises	residents
LM test	LMError	22.834***	2.616*	2.065
	R-LMError	2.266*	0.012	8.398***
	LMLag	22.438***	5.678**	14.184***
	R-LMLag	1.871*	3.075*	20.517***
LR test	LR-SAR	78.58***	31.65***	79.66***
	LR-SEM	77.57***	26.21***	88.10***
Hausman		-181.46	83.33***	43.62***

*,**,*** represent significance at the 10%, 5%, 1% level, respectively. Results in brackets are z-values.

Furthermore, this study refers to the model selection approach outlined by Elhorst (2015). [30]First, based on the significance of the LM test, whether both SEM and SAR models are deemed appropriate. Second, the LR statistic tests whether the SDM model can be simplified into the SEM or SAR model. If the results are highly significant (the Wald statistic yields the same results), it indicates that the SDM model cannot be simplified into the other two models. Third, the Hausman and joint significance tests indicate that the two-way fixed-effects SDM model is chosen for enterprises and residents. In contrast, for local governments, the random-effects SDM model is selected.[Note 3]

5.2 Local Governments

According to the regression results in Model (1) presented in Table 3, for both types of spatial weight matrices, regardless of whether the quadratic term of environmental governance is included or not, the spatial autoregressive coefficient ρ^1 which represents environmental pollution related to the core interests of local governments, is significantly positive at the 1% level. This indicates that environmental pollution exhibits spatial effects. When environmental pollution is more severe in one region, it significantly impacts the environmental pollution in neighboring regions. From the perspective of agglomeration economics, there are two possible reasons for the positive spatial coefficient: first, pollutants tend to spill over geographically, meaning that the more pollution in one region, the greater the diffusion of its pollution to adjacent regions; second, within the same region, there are often multiple interacting economic entities whose living and production are interconnected, resulting in the spatial agglomeration of environmental pollution. Regarding harm, governments in different regions have pollution diffusion effects, which implies their involvement in local environmental governance is indispensable(see Table 3).

Under the two types of spatial weight matrices, when environmental governance ZL is the core variable for local governments, it only significantly positively affects local environmental pollution without a spatial spillover effect. In theory, increasing the strength of governance should have led to a reduction in pollutant emissions. However, the empirical results show that pollutant emissions are still increasing. One possible explanation is that China has accumulated a vast historical burden of environmental damage, and the environment and the economy have not yet reached the turning point of the environmental Kuznets curve. Environmental pollution is still increasing with economic development, and environmental governance can only restrain the rate of increase but cannot directly reduce pollutant emissions. Additionally, environmental protection measures have not been for a long time and have not yet had long-term effects. According to international experience, environmental quality can only improve when environmental investment accounts for 2%-3% of GDP, [31]but the scale of investment in various regions of China is still relatively small, with the highest being only 0.99%. When the linear term, ZL, and the quadratic term, ZL^2, of environmental governance are considered, they have significant positive and negative effects on environmental pollution at the 1% level, respectively. This suggests that environmental governance can improve environmental pollution, but a substantial accumulation is required to diminish the marginal effect of pollution. The impacts of environmental governance $W \times ZL, W \times ZL^2$ in neighboring regions on local environmental pollution are insignificant and significantly negative, respectively. This indicates that after a certain extent of environmental governance strength, governments in different regions can benefit from the environmental governance in neighboring areas. Since spatial lag terms may ignore feedback information between adjacent regions, the partial derivatives proposed by LeSage and Pace (2009) [32]are used to obtain each core explanatory variable's direct and indirect effects. It can be observed that the direct and the overall effects of ZL and ZL^2 on pollution are significantly positive and negative, respectively. This implies that the relationship between environmental governance and local and overall environmental pollution follows an inverted U-shaped pattern, and governance efforts should be continuously strengthened. The indirect effects are significantly positive and negative under matrix $W1$, and only ZL^2 is significantly negative under matrix $W2$. This indicates that the spatial effects of environmental governance on local governments are more pronounced under the geographical distance matrix, and lower governance intensity may shift some pollution to nearby areas. With the improvement of governance measures, environmental governance will have a beneficial impact on nearby areas. Regarding benefiting, governments in different regions benefit from environmental governance and should participate in local environmental governance.

Under the two types of spatial weight matrices, the linear term JJ and quadratic term JJ^2 of economic development have significant positive and negative effects on environmental pollution, respectively. This suggests that as the economy develops, environmental pollution follows an inverted U-shaped pattern, initially increasing and then decreasing, which aligns with the Environmental Kuznets Curve. The regression coefficients of the industrial structure CY are significantly negative at the 1% level, indicating that a higher share of the tertiary industry is associated with lower environmental pollution. Environmental pollution is fundamentally caused by irrational production methods, with a disproportionately large share of high-energy and high-emission industries leading to increased pollution that may exceed the environmental carrying capacity. Therefore, upgrading and transiting the industrial structure can contribute to a green ecological environment. Opening-up level, DW, has a significant negative impact on environmental pollution at the 5% level, indicating that international openness facilitates the exchange of experiences and learning between regions and the transfer of pollution, effectively reducing the environmental pollution. Urbanization rate, CZ, and technological progress, JS, negatively affect environmental pollution, while population density has a positive effect, none of these effects are statistically significant. This suggests that accelerating urbanization, improving technology, and reducing population size can contribute to reducing pollution. However, at the current stage, these factors do not yet have significant impacts in China.

Table 3. Estimation results of the spatial relationship between eco-environment governance and multiple agents

	Local governments (Model 3)				Enterprises (Model 2)				Residents (Model 3)	
Indexes	$W1$		$W2$		$W1$		$W2$		$W1$	$W2$
ZL	0.0443*(1.79)	0.2006***(3.81)	0.4568*(1.83)	0.2042***(3.85)	0.5293**(2.23)	0.6795*(1.66)	0.4960**(2.19)	0.7205*(1.67)	-0.0731**(-2.00)	-0.0662*(-1.79)
ZL^2		-0.2207***(-3.50)		-0.2192***(-3.46)		-0.1332(-0.23)		-0.2294(-0.41)		
JJ	0.3345***(3.53)	0.3426***(3.65)	0.3562***(3.56)	0.3611***(3.63)	1.4170***(8.25)	1.4122***(8.24)	1.4112***(8.73)	1.4034***(8.72)	0.1400***(4.91)	0.1556***(5.49)
JJ^2	-0.0146***(-3.03)	-0.0149***(-3.11)	-0.0156***(-3.09)	-0.0157***(-3.13)						
CY	-0.0016**(-2.40)	-0.0018***(-2.82)	-0.0019***(-2.82)	-0.0021***(-3.15)	0.0059(0.86)	0.0053(0.76)	0.0081(1.26)	0.0073(1.13)	0.0038***(4.05)	0.0040***(4.15)
CZ	-0.0002(-0.55)	-0.0002(-0.48)	-0.0001(-0.24)	-0.0006(-0.16)	0.0153***(3.50)	0.0149***(3.41)	0.0138***(3.33)	0.0134***(3.24)		
DW	-0.0005**(-2.24)	-0.0005**(-2.33)	-0.0005**(-2.45)	-0.0006**(-2.52)	-0.0325***(-16.44)	-0.0323***(-16.41)	-0.0325***(-16.88)	-0.0323***(-16.79)		
JS	-0.0033(-1.30)	-0.0026(-1.03)	-0.0037(-1.42)	-0.0030(-1.16)	0.3095***(12.65)	0.3100***(12.61)	0.3057***(12.68)	0.3057***(12.64)		
RK	0.0042(0.81)	0.0045(0.88)	0.0041(0.77)	0.0041(0.78)					-0.0080(-0.97)	-0.0098(-1.17)
WS									-0.0272***(-	-0.0301***(-

									4.90)	5.34)
YL									0.3252***(6.68)	0.3677***(7.44)
JY									0.0838***(4.64)	0.0750***(4.16)
$W \times ZL$	-0.0947(-1.38)	0.2705 (1.41)	-0.1457**(-1.96)	0.0914 (0.45)	-0.7538(-0.46)	-6.7589**(-2.01)	-3.3159**(-2.06)	-10.2309***(-3.06)	-0.5351**(-2.10)	-0.5455**(-1.96)
$W \times ZL^2$		-0.7596** (-2.29)		-0.5760*(-1.67)		9.0819**(2.03)		11.3357**(2.33)		
ZL (direct effect)	0.0383(1.46)	0.2461*** (4.12)	0.0326(1.22)	0.2364***(3.77)	0.5570(2.32)	0.8372*(1.65)	0.5758**(2.50)	0.9485*(1.91)	-0.0837**(-2.12)	-0.0776*(-1.94)
ZL^2 (direct effect)		-0.3197***(-4.00)		-0.3132***(-3.49)		-0.3483(-0.58)		-0.4917(-0.85)		
ZL (indirect effect)	-0.2290(-0.87)	1.4817** (2.16)	-0.4521(-1.46)	0.9855 (1.18)	-0.6763(-0.55)	-5.0996**(-2.13)	-2.6004**(-2.04)	-7.7340***(-3.09)	-0.8084**(-2.15)	-0.8267**(-2.06)
ZL^2 (indirect effect)		-3.2542***(-2.61)		-2.9522*(-1.77)		6.6669**(2.07)		8.5120**(2.39)		
ZL (total effect)	-0.1907(-0.70)	1.7278** (2.42)	-0.4195(-1.31)	1.2219 (1.41)	-0.1193(-0.09)	-4.2624*(-1.78)	-2.0246(-1.55)	-6.7855***(-2.70)	-0.8921**(-2.27)	-0.9043**(-2.16)
ZL^2 (total effect)		-3.5739***(-2.75)		-3.2654*(-1.89)		6.3185*(1.95)		8.0203**(2.24)		
ρ^1、ρ^2、ρ^3	0.7495***(18.81)	0.7247***(17.12)	0.7664***(19.42)	0.7548***(18.61)	-0.4674***(-2.99)	-0.4555***(-2.92)	-0.4207***(-3.59)	-0.4129***(-3.54)	0.2961**(2.41)	0.3000**(2.56)
R^2 - *within*	0.3565	0.4282	0.3281	0.3647	0.6826	0.6779	0.6725	0.6610	0.9125	0.9219
LogL	849.9424	858.4511	843.5080	850.4076	-386.5101	-384.3048	-396.0602	-392.9102	719.0805	721.8334
Model effect	Individual random effect				Two-way fixed effect				Two-way fixed effect	
N	600				600				570	

*,**,*** represent significance at the 10%、5%、1% level, respectively. Results in brackets are z-values.

5.3 Enterprises

Based on the regression results of enterprises in Model 2 in Table 3, under both types of spatial weight matrices, the spatial autoregressive coefficient ρ^2 which represents the Green Total Factor Productivity (GTFP) related to the core interests of enterprises is significantly negative at least at the 5% level. This suggests that, with the joint effects of other factors, an increase in GTFP in neighboring areas will inhibit green development in the local area. Moreover, when just considering ecological environment governance ZL, its coefficients are significantly positive at the 5% level. The indirect effects of spatial lag terms $W \times ZL$ and ZL are significantly negative at the 5% level under the geographic-economic weight matrix. This indicates that ecological environment governance positively impacts the GTFP in the local region but negatively impacts the surrounding regions. Comprehensively, the possible reasons behind these findings are that within a region, ecological environment governance or regulatory measures would stimulate enterprises to innovate in environmental protection technologies. This offsets the cost burden imposed by environmental regulations through increased productivity and effectively reduces pollution, aligning with the "Porter Hypothesis". [33]Besides, due to different and asymmetric ecological environment governance between regions, there is an increased transfer of polluting industries among regions. In other words, the local regions' ecological environment governance results in industrial structural upgrades or forces polluting industries to relocate, creating a "pollution refuge effect" in surrounding areas, leading to the green squeezing of enterprises in these areas. [34]

Including the quadratic term of ecological environment governance, ZL^2, the regression coefficient for ZL remains significantly positive, while the coefficient for ZL^2 is negative but insignificant. This suggests that ecological environment governance is linearly related to local Green Total Factor Productivity (GTFP). However, it is essential to be cautious about excessively stringent ecological environment governance, as it may lead to a "law of diminishing returns" and be detrimental to enterprise development. The coefficients for $W \times ZL, W \times ZL^2$ are both significantly negative, at least at the 5% level, indicating that when the strength of ecological environment governance is low. However, as the scale of governance expands, knowledge, technology, and human resource capital may diffuse, benefiting the green development of enterprises in surrounding areas. The direct and indirect effects of ZL and ZL^2 align with the discussion above, indicating that strengthening ecological environment governance consistently affects local and surrounding GTFP. Notably, the significance is more substantial under the geographic-economic weight matrix, and the total effects of ZL and ZL^2 are significantly negative and positive, respectively. This suggests that if mild, short-term ecological environment governance measures are taken, they will only produce a short-lived increase in local GTFP. The "push and pull" dynamics of pollution industries between regions, coupled with path dependency, will significantly reduce enterprises' overall regional green transition. On the contrary, if severe and sustained ecological environment governance is implemented, it will lead to a region-wide green production structure. Therefore, from a profit-seeking and risk-avoidance perspective, when a region undergoes ecological environment governance, surrounding enterprises should participate and ensure its continuity. Otherwise, they may suffer short-term losses in GTFP and miss out on the spatial dividends that promote long-term, stable enterprise development.

Under both types of spatial weight matrices, economic development level JJ, urbanization rate CZ, and technological progress JS, all have significant positive effects on Green Total Factor Productivity (GTFP). This suggests that accelerating economic development, promoting urbanization, and advancing technological levels are conducive to enterprises' green transition and development. As these three indicators improve, people's environmental awareness and methods will also further enhance, leading to better energy conservation, emissions reduction, and responsibilities for pollution control among enterprises. The level of opening-up DW has a significant negative impact on GTFP at the 1% level. Combined with the spatial adverse effects of GTFP and its negative impact on regional pollution, this indicates that the level of opening-up has brought about pollution transfer rather than benefits in mutual green technology. This aligns with the conclusion of Grossman and Krueger (1991) [36]that the impact of trade on green development results from various effects such as scale, income, structure, industry, technology, and policy, and its trend is uncertain, primarily depending on the size and direction of different effects. The coefficients for industrial structure CY are not significant, suggesting that increasing the proportion of the tertiary industry does not directly impact the overall GTFP of enterprises. Due to the unique characteristics of China's earlier development and the limitations of the current economic development, most regions are still in rapid industrialization and urbanization, with a high dependence on industry. The adverse environmental effects of the secondary industry outweigh the low-pollution industries, such as emerging strategic industries and modern services. Therefore, the impact of the industrial structure transition has not yet manifested, and it should be improved through technological innovation, quality enhancement, and efficiency improvement to increase GTFP.

5.4 Residents

Based on the regression results of residents in Model 3 in Table 3, under both types of spatial weight matrices, the spatial autoregressive coefficient ρ^3, which represents the number of outpatients related to the core interests of residents, is significantly positive at the 5% level. This suggests that residents' health exhibits strong spatial positive influences, with a noticeable spatial clustering of health levels. Environmental governance ZL is significantly negative at the 5% level (geographical distance weight matrix) and the 10% level (geographical economic weight matrix). [Note 4] Its spatial lag term $W \times ZL$ is significantly negative at the 5% level under both matrices. This indicates that residents' health in the local area benefits from the improvement of local eco-environmental quality and the eco-environmental governance in neighboring areas through spatial spillover. The number of outpatients is a tangible reflection of regional residents' health changes. Environmental governance of local and neighboring areas can not only obstruct pollution diffusion to improve the quality of eco-environmental resources directly consumed by residents, such as air and water, but also improve forests, soil, and biodiversity to enhance the supply of upper-level buildings. Therefore, environmental governance has spatial effects. In addition, the direct and indirect effects of environmental governance ZL are both significantly positive, indicating that environmental governance simultaneously affects the health of the local area and neighboring areas. It is evident that when one region carries out environmental governance, residents in other regions will benefit from it and should participate in local eco-environmental governance.

Under both types of spatial weight matrices, economic development level JJ, industrial structure CZ, medical level YL, and education level JY, all have significant positive impacts on the number of outpatients at the 1% level. This suggests that more developed economies and outpatients can be attributed to increased incomes, making residents more concerned about their health and afford medical treatment. Moreover, as social and economic develops, significant changes in people's lifestyles, such as fatigue from work, lack of exercise, and increased tobacco and alcohol consumption, lead to frequent suboptimal health. Furthermore, according to the results of local governments, when the impact of the economy on environmental pollution has not yet reached a turning point, economic growth leads to increased pollution, causing damage to residents' health and thereby increasing the number of outpatient visits. The increase in the proportion of the tertiary industry significantly raises the number of outpatients, possibly because China's health service industry has developed rapidly in recent years, increasing the demand for residents' health services and guarantees. The increase in physicians per thousand people indicates the continuous enrichment of medical resources, relieving difficulties in medical treatment and reducing medical expenses, allowing residents to be cured more confidently. Similarly, the improvement in education helps enhance the literacy and health awareness of the public, improving residents' health quality, which in turn leads to an increase in outpatients. Public health investment WS representing the proportion of fiscal expenditure on medical health, social security, disease prevention and control, is significantly negative at the 1% level. This indicates that a greater investment leads to fewer outpatients. In practice, this reflects residents' concerns about their health. The more attention they pay to their health, the better they can prevent and prepare for potential health issues, reducing the frequency of treatments. The coefficient for population density RK is negative but insignificant, indicating that population agglomeration is favorable for residents' health. Still, the scale effect proposed by previous studies, which can lead to fewer pollution dividends, has not yet manifested. [35]

5.5 Robust Test

In summary, local governments, enterprises, and residents are all spatial stakeholders in environmental governance. Governments and residents in different regions should participate in the environmental governance of local governments based on benefits, while enterprises should also be involved based on profit and risk avoidance. In all regression results, the indirect effects of environmental governance (local governments, ZL^2 for enterprises, and ZL for residents) are more significant than the direct effects. Under the geographical distance weight matrix, the indirect effects are approximately 10 times, 19 times, and 10 times larger than the direct effects, respectively, while under the geographical-economic weight matrix, the ratios are 9 times, 17 times, and 11 times, respectively. This further illustrates that as the strength of environmental governance advances, ecosystem services are transferred across regions and interact with other external factors. The spatial spillover effect is stronger than the direct effect on the local area. Furthermore, comparing the regression results of different entities under the two types of spatial weight matrices, it is found that the coefficients R^2 and Log-likelihood values of these matrices are very close, respectively. Still, the result of local governments is more optimal under the geographical distance matrix. Its spatial term is more significant, and the regression coefficients are larger, indicating that environmental pollution shows a stronger geographical correlation and adjacent governments should collaborate in environmental governance. For enterprises and residents, the results are more favorable under the geographical-economic weight matrix, indicating that enterprises and residents in economically developed areas that are geographically close should collaborate in environmental governance. The similar conclusions under the two types of spatial weight matrices, to some extent, confirm the reliability and robustness of the study. The study further tests the robustness by changing the core indicator variables based on the results with the more optimal spatial weight matrix. Table 4 presents the regression results for environmental governance represented by the rate of investments in industrial pollution and value-added of industry. The trend of impact and significance of the direct effect, indirect effect, and total effect of environmental governance are consistent with those in Table 3, indicating that the conclusions remain robust even after changing the core indicator variables(see Table 4).

Table 4. Robustness test

Indexes	Local governments (Model 3)	Enterprises (Model 2)	Residents (Model 3)
Spatial weighted matrices	$W1$	$W2$	$W2$
ZL^*	0.0649***(3.62)	0.1453*(1.92)	-0.0242*(-1.76)
ZL^{*2}	-0.0218***(-2.90)	0.6325(1.15)	
$W \times ZL^*$	0.0177(0.29)	-20.4661***(-6.32)	-0.3482***(-3.27)
$W \times ZL^{*2}$	-0.0575(-1.47)	24.1891***(5.20)	
ZL^* / ZL^{*2} (direct effect)	0.0730***(3.58)/-0.0305***(-3.10)	0.3125*(1.65)/0.0828(0.15)	-0.0317**(-2.08)
ZL^* / ZL^{*2} (indirect effect)	0.2492(1.06)/-0.2763*(-1.74)	-14.5527***(-5.77)/17.1478***(5.00)	-0.5173***(-3.01)
ZL^* / ZL^{*2} (total effect)	0.0322(1.32)/-0.3068*(-1.85)	-14.2402***(-5.59)/17.2306***(5.00)	-0.5490***(-3.07)
ρ^1、ρ^2、ρ^3	0.7414***(18.32)	-0.4515***(-3.91)	0.3***(2.57)

R^2 - *within*	0.3812	0.6262	0.9168
Log-likelihood	856.6965	-384.5855	722.2405
Types of model	Individual random effect	Two-way fixed effect	Two-way fixed effect

*、**、*** represent significance at the 10%、5%、1% level, respectively. Results in brackets are z-values.

6. Conclusions and Recommendations

This study used panel data from 2001 to 2020 for 30 provinces (regions) in China to investigate the spatial relationships between various entities and environmental governance. Environmental governance served as the core explanatory variable. In contrast, environmental pollution, green total factor productivity, and resident health were selected as dependent variables from the perspectives of local governments, enterprises, and residents. The objective was to obtain empirical evidence for the participation of diverse groups in interregional environmental governance. The main research findings are as follows:

1. For the local governments, environmental pollution exhibits spatial clustering characteristics, with pollution tending to be more severe in areas with higher spillover effects on surrounding regions. From a perspective of potential harm, governments in other regions should participate in the ecological environment governance of conservation areas. An inverted "U"-shaped spatial relationship exists between environmental governance and interregional environmental pollution. When governance strength is low, some pollution may shift to neighboring areas. However, positive effects on neighboring regions become apparent as governance intensity increases. Therefore, governments in other regions benefit from local environmental governance and should participate.

2. For the enterprises, the spatial lag coefficients of green total factor productivity and the first-order spatial lag coefficient of environmental governance are both significantly negative. In contrast, environmental governance's second-order spatial lag coefficient is significantly positive. This suggests a spatial "U"-shaped relationship between environmental governance and green total factor productivity in neighboring areas. In the initial stages of governance, differentiated and asymmetric policy regulations between regions may exacerbate the transfer of pollution industries between regions. However, with the expansion of the governance scale, various forms of social capital may diffuse, benefiting the green development of neighboring areas. Therefore, enterprises in other regions should participate in environmental governance to supplement governance efforts, ensuring the long-term stability of environmental governance and avoiding losses in green total factor productivity.

3. For the residents, health levels exhibit strong positive spatial effects and evident spatial clustering. Environmental governance and its spatial lag coefficients are significantly negative, indicating that residents in the local area benefit from improvements in local ecological environment quality and the spillover effects of environmental governance in neighboring areas. Furthermore, comparing the direct and indirect effects of environmental governance, increased governance intensity in neighboring areas is more beneficial for improving the health of residents. Therefore, when a region undergoes environmental governance, residents in other regions also benefit and should participate in local eco-environmental governance.

4. Comparing the direct and indirect effects of environmental governance from various perspectives, increased governance intensity in neighboring areas significantly impacts the degree of local environmental pollution, green total factor productivity of enterprises, and resident health. Environmental governance exhibits strong spatial spillover effects. Regarding the strength of the spatial weight matrix, interregional environmental governance among local governments should be based on geographical distance rather than economic development level. This means that adjacent regions should establish close connections to promote environmental governance collaboratively, breaking away from spatial functional zoning constraints. For enterprises and residents in other regions participating in eco-environmental governance, geographical and economic distances should be considered. Encouraging enterprises and residents in economically developed neighboring areas to participate collaboratively can overcome challenges related to perceived benefits or losses associated with geographic distance and difficulties in action due to economic similarity.

Based on the conclusions above, the following recommendations on policy are proposed:

1. Enhance the intensity of environmental governance. Implement a consciousness of environmental protection that involves every citizen rather than being the special responsibility of specific regions. To

leverage the positive role of regulatory governance, the following steps should be taken: First, identify and address "weak areas" of ecological and environmental protection by continuously seeking them out in policy. The development of national parks, key national ecological function zones, and other projects is not the responsibility of one region. All groups, from the central government to surrounding regions and economically developed areas, should take necessary actions and bear the associated costs to create a sound external environment for implementing various regulatory policies and establishing a solid institutional foundation. Second, gradually increase the intensity of ecological environment regulation in all regions. Plan spatial areas and collaborate with neighboring regions for joint prevention and control. This involves the government's leadership, inter-departmental coordination, and social participation. Formulate a seven-level governance structure consisting of national, regional, provincial, municipal, county, township, and village levels, implementing layered control and supervision. This framework will create a clear division of responsibilities, ensure coordinated actions, maintain strict regulation, and provide adequate protection, thereby forming a comprehensive, cross-cutting management mechanism. Third, promote positive cooperation, rewards, and penalizes between ecological conservation areas. Strictly control total pollutant emissions, create a model area, and then have other areas imitate. Avoid adverse phenomena like ‘free riding’ and bottom-line competition for funds and talents, which can significantly reduce the effectiveness of ecological environment governance.

2. Strengthen the identification, management, and enhancement of the externality of environmental governance between regions. Environmental governance significantly affects the pollution of surrounding areas, the green total factor productivity of enterprises, and the health level of residents. These effects emphasize the importance and necessity of local governments, enterprises, and residents in formulating, participating in, and implementing environmental governance. However, the absence of external management of interregional environmental governance has led to mutual evasion of responsibility among surrounding areas and various groups. To address this, decision-making related to policies involving diverse participation in ecological environment governance should fully consider the spatial spillover effects of governance. Effective communication mechanisms should be established with neighboring governments, enterprises, and residents to resolve potential policy and interest conflicts between regions. Shared interests among diverse entities should be highlighted. Allow for more scientifically reasonable policy formulation and goal planning for multiple participants. Avoid the singular decision-makers and constrained policy perspectives in environmental regulation decision-making, aiming to achieve a "1 + 1 > 2" policy effect. Specifically, ecological conservation areas can proceed in stages to manage different ecological resources. Discussions should be held with neighboring local governments, enterprises, and residents to determine the priority and sequence of governance efforts. This approach ensures the maximum benefit from ecological spillover effects.

3. Diversify and optimize the measures for the participation of multiple entities in environmental governance. First, mobilize different groups' participation in ecological environment governance according to regional requirements. For instance, the local governments prioritize the involvement of neighboring governments in ecological environment governance rather than imposing restrictions on economically developed regions. The enterprises and residents should also encourage participation from economically developed areas. Second, pave the way for participation based on multiple entities' diverse spatial interest indicators. Governments, enterprises, and residents in surrounding areas can quantify their financial or material investments into ecological environment governance based on their average benefits. For example, considering the regression results mentioned above, under the spatial weight matrix with more optimal spatial spillover effects, the indirect effects of ecological environment governance for local governments, enterprises, and residents are -3.2542, 8.5120, and -0.8267, respectively. It means for every unit increase in ecological environment governance, the positive external spillover benefits to the surrounding regions regarding environmental quality, enterprise green total factor productivity, and resident health level are 3.2542, 8.5120, and 0.8267, respectively. Therefore, the costs incurred by local governments reducing pollution by 3.2542, enterprises increasing green total factor productivity by 8.5120, and residents improving health by 0.8267 can be calculated and then involve these entities in ecological environment governance by compensating ecological conservation areas.

Fund Project

1. General Project of Humanities and Social Sciences Research of the Ministry of Education, "Research on the Path and Mechanism Construction of Ecological Product Value Realization in Key Ecological Function Areas in Western China" (19YJCZH088);

2. Youth Project of Shaanxi Natural Science Foundation, "Research on the Quality Measurement of Digital Economy Development in Shaanxi and Its Effects on Rural Revitalization" (2022JQ-745);

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Notes

Note 1. "Scale" is a commonly used term in geography, ecology, history, etc. It refers to the time or spatial unit when conducting various observations. It can also refer to a particular phenomenon's spatial and temporal range. Refer to Wu Jianguo: "Landscape Ecology," published by Higher Education Press in 2022, pages 1-14.

Note 2. Spatial autocorrelation was quantified using Moran's I (range: -1 to 1; $I > 0$ implies clustering) and Geary's C (range: 0–2; $C < 1$ indicates similarity).

Note 3. In theory, the Spatial Durbin Model (SDM) combines the advantages of both the Spatial Error Model (SEM) and the Spatial Autoregressive (SAR) Model. It can consider the spatial dependence of the dependent and the explanatory variables while accounting for the spatial impacts of random error shocks. This further underscores the rationality and superiority of the model chosen for this study.

Note 3. If adding the quadratic term for environmental governance ZL^2 results in both the linear and quadratic terms being statistically insignificant, it suggests no significant nonlinear relationship between environmental governance and the dependent variables. Therefore, the results are not shown.