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Analysis of Spatial and Temporal Characteristics and Influencing Factors of Agricultural Surface Pollution in the Yangtze River Economic Zone--Based on Three Perspectives of Government, Enterprise and Agriculture

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Abstract: In order to better realize rural revitalization, this paper analyzes the spatial and temporal characteristics and influencing factors of agricultural surface source pollution in the Yangtze River Economic Belt from the three perspectives of government, enterprise and agriculture by using the spatial Durbin model and the dynamic GMM method in the period of 2006-2021, and further researches the threshold characteristics of the distortion of the factor market on the agricultural surface source pollution under the different strengths of environmental regulation. The results show that there is a positive spatial correlation between agricultural surface pollution in the Yangtze River Economic Belt, and government environmental regulation, input factor market distortion and labor force transfer all have a significant impact on agricultural surface pollution. Among them, factor market distortion has a significant spatial spillover effect on agricultural surface pollution in the Yangtze River Economic Zone, and has a significant single-threshold effect on environmental regulation. Accordingly, the government should strengthen environmental regulation, continuously improve the agricultural factor market mechanism, and pay attention to the construction of talents to provide support for rural revitalization.

Keywords: agricultural surface pollution; Yangtze River Economic Zone; spatial and temporal characteristics; threshold effect

1. Introduction

As a major agricultural country in the world, China has made great achievements in agricultural development in recent years. According to the Ministry of Agriculture and Rural Development, China's agricultural trade totaled 334.32 billion U.S. dollars in 2022, a year-on-year increase of 9.9 percent. As the scale of agricultural trade continues to expand, it also brings increasingly serious environmental problems, and agricultural surface pollution has become an important factor hindering the sustainable development of China's agriculture and the realization of the goal of building a better countryside. At present, China's agricultural surface pollution is characterized by decentralization, uncertainty and lagging [1], and it is difficult to determine the main body of pollution control and supervision in the process of governance, resulting in unbalanced participation of the main body, and unsatisfactory governance effect. At this stage, the prevention and control of agricultural surface pollution in China still has a long way to go. For a long time, the Yangtze River Economic Zone, as the most important agricultural production base in China, has been realizing rapid economic growth, while the degree of agricultural surface pollution is also increasing, which seriously restricts the sustainable economic development and ecological protection of the Yangtze River Economic Zone. At the same time, the "14th Five-Year Plan" period is a period of in-depth promotion of the prevention and control of agricultural surface pollution, as well as the Yangtze River

Economic Belt ecological environmental protection and the realization of the green development of the period of attack [2]. Therefore, as a key area of concern for the green development of agriculture in the new period, this paper selects the panel data of the Yangtze River Economic Belt for example analysis [3].

Since the agricultural environment has the attribute of public goods, the government should be the main governing body of agricultural surface pollution, and the environmental regulation it adopts largely influences whether the problem of agricultural surface pollution can be effectively solved [4]. As far as the market is concerned, once the input factor market fails, it will exacerbate the use of inferior products by farmers to a certain extent, and further aggravate agricultural surface pollution. At the same time, in a large country with small farmers, China's farmers are the largest number of agricultural producers, with the largest total production and operation area, which is the potential manufacturing body of agricultural surface pollution [5]. The report of the 19th CPC National Congress mentioned that it is necessary to build "an environmental governance system in which the government, enterprises, society and the public jointly participate". Since then, the Ministry of Ecology and Environment, Ministry of Agriculture and Rural Development jointly issued the "agricultural surface pollution governance and supervision and guidance implementation program (for trial implementation)" also mentioned that we should actively promote the "government + association + farmers" model of agricultural surface pollution governance. Various programmatic documents as well as governance initiatives have shown that China's agricultural surface pollution problem can be effectively solved, mainly from the government, the market and farmers three main body, the development and implementation of targeted policy recommendations.

Based on this, scholars at home and abroad have also studied the problem of agricultural surface pollution and its influencing factors from different perspectives. From the government perspective, relevant studies have shown that the improvement of the intensity of government environmental management is conducive to improving the effectiveness of environmental pollution management [6]. Similar studies have also confirmed that the development of appropriate environmental regulation is an important means of curbing agricultural surface pollution [7-9], for example, the government can use agricultural insurance as an important policy tool to promote the green transformation of agriculture, so as to effectively reduce the degree of agricultural surface pollution [10]. At the same time, environmental regulatory policies can also force the progress of agricultural production technology, so as to reduce the degree of agricultural surface source pollution [11]. Under the market perspective, existing studies have mainly focused on the analysis of input factor markets. It was found that with the progress of agricultural technology, the input of agricultural production factors within the market increased, which brought about a larger scale of agricultural production while also aggravating agricultural surface source pollution [12]. At the same time, fertilizer market distortion also has a significant stimulating effect on the discharge of agricultural surface pollution emissions [13]. Farmers perspective, it has been pointed out that the transfer of rural labor force will lead to the reduction of agricultural labor force, thus forcing farmers to choose chemical fertilizer to replace the original organic fertilizer, leading to the increase of fertilizer application per unit area in rural areas, which in turn exacerbates the agricultural surface pollution [14], and actively promote the transfer of land from farmers is one of the effective ways to alleviate this pollution [15].

To summarize, most of the existing studies on agricultural surface pollution are based on the whole country or a certain province as the research object, and seldom focus on the Yangtze River Economic Belt region; most of the studies on the influencing factors are from a single perspective, and there is a lack of joint research from the three perspectives of the government, enterprises and farmers; there are fewer studies on the market of the input factors, and there is a lack of probing whether it is a linear or nonlinear impact on the environmental pollution. Based on this, with reference to the research of scholars at home and abroad, this paper takes the Yangtze River Economic Belt as the research object from the perspectives of the government, market and farmers, and discusses the spatial and temporal characteristics and influencing factors of agricultural surface pollution by establishing a spatial econometric model, so as to provide theoretical support for the promotion of the modernization of the Yangtze River Economic Belt's agriculture, the enhancement of the capacity of the governance of agricultural surface pollution, and the establishment of the governance system. Compared with existing studies, the main contributions and possible innovations of this paper are as follows: first, this paper focuses on the Yangtze River Economic Belt rather than the whole country or a certain province or city, and focuses on the current situation of agricultural surface pollution in this region to provide policy suggestions for it to realize sustainable economic development and ecological protection. Second, focusing on the agricultural industry, the paper explores the impacts of environmental regulation, factor market distortion and labor transfer on agricultural surface pollution from the perspectives of government, market and farmers, which enriches and expands the new perspectives. Thirdly, the spatial Durbin and threshold effect models are used to investigate the spatial spillover effect of factor market distortion on agricultural surface pollution and the threshold effect of factor market distortion on agricultural surface pollution under different strengths of environmental regulations. The relationship between factor market distortion and agricultural surface pollution is clarified to provide targeted policy recommendations for promoting pollution management and realizing rural revitalization. Fourth, due to the time lag and negative externality of environmental pollution, errors may arise when conducting the analysis of influencing factors. In this paper, the robustness test using the dynamic GMM method takes the effect of the lagged term into account, which corrects this error and makes the conclusion more credible.

2. Materials and Methods

2.1. Research methodology

2.1.1. spatial autocorrelation model

Before using spatial econometric regression, it is first necessary to test the spatial autocorrelation of agricultural surface pollution in the Yangtze River Economic Belt in China. In this paper, the global Moran index and local Moran index are used to more comprehensively characterize the spatial distribution and aggregation of agricultural surface pollution in the Yangtze River Economic Zone as a whole and in each province and city. Before calculating the Moran index, the spatial weight matrix needs to be determined, and its main selection methods are based on collinearity and distance. Since the provinces and cities in the Yangtze River Economic Belt analyzed in this paper have common boundaries, this paper selects the 0-1 neighboring weight matrix W. The formula is expressed as follows:

Spatial weighting matrix:

$$\mathrm{W}_{ij} = \begin{cases} 1, & \text{regions i and j are adjacent} \\ 0, & \text{regions i and j are not adjacent} \end{cases} \tag{1}$$

Global Moran's I index:

$$\text{Moran's I} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - \bar{x})(x_j - \bar{x})}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \tag{2}$$

Lisa index:

$$I_i = \frac{y_i - \bar{y}}{S^2} \sum_{j=1}^{n} W_{ij}(y_i - \bar{y}) \tag{3}$$

$$S^2 = \frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2, \quad \bar{y} = \frac{1}{n}\sum_{i=0}^{n} y_i \tag{4}$$

Where x_i, x_j are the observed sample values of province i and province j in turn, n is the number of provinces and cities, and S^2 is the sample variance. w_{ij} is the spatial weight matrix, when there is a neighboring boundary between city i and city j, it is recorded as 1, and if there is none, it is recorded as 0. The Moran's I index takes a value between -1 and 1, and the larger the absolute value is, the stronger is the spatial correlation.

2.1.2. Spatial Durbin model

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In order to further examine the influencing factors of agricultural surface pollution in the Yangtze River Economic Belt under the three perspectives of government, enterprise and agriculture, with reference to the studies of existing scholars [16-17], this paper sets up the Spatial Dubin Modle (SDM) for analyzing the influences of the explanatory variables on the agricultural surface pollution, whose expression is as follows :

$$LnP_{it} = \beta_0 + \rho W_{ij}LnP_{it} + \beta_1 ER_{it} + \beta_2 D_{it} + \beta_3 LM_{it} + \beta_4 Control_{it} + \delta_1 W_{ij}ER_{it} + \delta_2 W_{ij}D_{it} + \delta_3 W_{ij}LM_{it} + \delta_4 W_{ij}Control_{it} + \mu_i + v_t + \varepsilon_{it} \quad (5)$$

where subscripts i and t denote province and year, respectively, P_{it} is the explanatory variable agricultural surface pollution, ER_{it} is environmental regulation, D_{it} is fertilizer factor market distortion, LM_{it} is labor migration, $Control_{it}$ is the control variable, W_{ij} is the spatial weight matrix. β is the corresponding coefficient, ϱ is the spatial autocorrelation coefficient, u_i is the individual effect, v_i is the temporal effect, ε_{it} is the residual.

2.1.3. GMM methods for dynamic systems

In order to avoid the endogeneity problem that may be triggered by the traditional static model and to consider the possible dynamic dependence problem of agricultural surface pollution, the lagged term of agricultural surface pollution was introduced as an explanatory variable on the basis of the model (8) equation, and the dynamic system GMM method was used to conduct the robustness test, which is given in the following formulas:

$$LnP_{it} = \alpha + \beta_0 LnP_{i,\ t-1} + \beta_1 ER_{it} + \beta_2 D_{it} + \beta_3 LM_{it} + \beta_4 Control_{it} + \mu_i + v_t + \varepsilon_{it} \quad (6)$$

The variables in Eq. are consistent with the above model and will not be repeated here, where $P_{i,\,t-1}$ denotes the lag period of agricultural surface pollution.

2.1.4. Threshold model

In order to further examine the nonlinear impact of factor market distortion on agricultural surface pollution, this paper draws on the threshold effect test of Hansen [18] to construct a threshold model with environmental regulation as the threshold variable, with the following formula:

$$\mathrm{LnP_{it}} = \beta_0 + \beta_1 \mathrm{D_{it}} \times \mathrm{I}(\mathrm{ER_{it}} \le \tau_1) + \cdots + \beta_n \mathrm{D_{it}} \times \mathrm{I}(\tau_{n-1} < \mathrm{ER_{it}} \le \tau_n) + \beta_{n+1} \mathrm{D_{it}} \times \mathrm{I}(\mathrm{ER_{it}} > \tau_n) + \beta_c \mathrm{Control_{it}} + \varepsilon_{it} \quad (7)$$

where τ is the threshold to be estimated, I(.) is the schematic function, and if the (.) expression within is true, then I takes the value of 1. Otherwise it is 0.

2.2. Variable Selection and Data Source

This paper refers to the research of existing scholars, respectively, from the government, the market and farmers three perspectives, each selected a representative indicator to analyze the influence factors of agricultural surface pollution in the Yangtze River Economic Zone, the specific indicators are selected as follows.

2.2.1. Explained variable: agricultural surface source pollution (lnp)

At this stage, the environmental quality decline of agricultural soil, water and atmosphere caused by the large-scale use of chemical fertilizers has become the most important causative factor of agricultural surface source pollution in China [19]. In this paper, according to the current situation of agricultural life and production in the Yangtze River Economic Zone, the ratio of fertilizer application to the sown area of crops was used to obtain the degree of agricultural surface source pollution.

2.2.2. Explanatory variables

(1) Environmental regulation (ER)

Based on the index refinement and availability, this paper adopts the proportion of the environmental protection investment of the completed environmental protection acceptance project

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and the gross agricultural product in the year to measure the intensity of environmental regulation [20-21]. The larger the proportion of total environmental protection investment, the greater the strength of local government's environmental protection. In the study of threshold effect, it is used as a threshold variable.

(2) Factor market distortion (D)

The agricultural surface pollution discussed in this paper is mainly fertilizer pollution, so the fertilizer factor market is selected as a representative of the choice of input factor market,. On the basis of existing research [13], this paper first uses the agricultural production function to estimate the marginal output of fertilizer, and then calculates the distortion index of the fertilizer factor market based on the ratio of the marginal output of fertilizer to the real price of fertilizer. In the study of threshold effect, it serves as the core explanatory variable.

In the analysis of the input-output relationship of production factors, the more commonly used are the three production functions of Cobb Douglas (C-D), constant elasticity of substitution (CES) and transcendental logarithm (Translog). Due to the strong assumption of unit elasticity of substitution, the use of the C-D function may produce estimation bias problems for two or more outputs and inputs, and the CES function may also produce parameter estimation difficulties due to the nonlinearity of the function. The Translog production function, on the other hand, is a log-quadratic form of inputs and outputs, a functional form that allows for a wider range of substitution and switching patterns relative to constant substitution and switching elasticities [22]. Therefore, this paper on the measurement of the degree of distortion of the fertilizer factor market, with reference to the research of existing scholars [23-27], first of all, using the Translog production function to estimate the value of the marginal output of fertilizer, and then using the ratio of the marginal output of fertilizer to the real price of fertilizer to calculate the distortion index of the fertilizer factor market. The specific calculation method is as follows:

The use of beyond the logarithmic production function form to construct the agricultural production function model:.

$$\begin{aligned}\mathrm{lnY}_{it} = {} & \beta_0 + \beta_m lnM_{it} + \beta_l lnL_{it} + \beta_d lnD_{it} + \beta_k lnK_{it} + \beta_g lnG_{it} + \beta_{mm}(lnM_{it})^2 + \beta_{ll}(lnL_{it})^2 \\ & + \beta_{dd}(lnD_{it})^2 + \beta_{kk}(lnK_{it})^2 + \beta_{gg}(lnG_{it})^2 + \beta_{ml} lnM_{it} lnL_{it} + \beta_{md} lnM_{it} lnD_{it} \\ & + \beta_{mk} lnM_{it} lnK_{it} + \beta_{mg} lnM_{it} lnG_{it} + \beta_{ld} lnL_{it} lnD_{it} + \beta_{lk} lnL_{it} lnK_{it} + \beta_{lg} lnL_{it} lnG_{it} \\ & + \beta_{dk} lnD_{it} lnK_{it} + \beta_{dg} lnD_{it} lnG_{it} + \beta_{kg} lnK_{it} lnG_{it} + \varepsilon_{it}\end{aligned} \tag{8}$$

Marginal output of fertilizer is estimated by OLS measure:

$$MPD_{it} = \frac{\partial lnY_{it}}{\partial lnD_{it}} = \beta_d + \beta_{dd} lnD_{it} + \beta_{md} lnM_{it} + \beta_{ld} lnL_{it} + \beta_{dk} lnK_{it} + \beta_{dg} lnG_{it} \tag{9}$$

Degree of fertilizer market distortion = marginal output of fertilizer/real price of fertilizer.

$$\mathrm{Dis} = \frac{MPD_{it}}{p_{it}} \tag{10}$$

Where the output variable of Translog production function is the total agricultural GDP, the input variables are sown area'M', labor transfer'L', fertilizer application'D', total power of agricultural machinery'K' and effective irrigated area'G'. Yit denotes the total agricultural GDP of the ith city in the tth year, and so on for the rest of the variables, and ε is the random disturbance term.

(3) Labor Migration (LM)

This paper uses the ratio of the number of rural migrant workers to the total number of rural laborers. The labor force transfer has a factor substitution effect on fertilizer inputs of farm households, and the labor force transfer will increase the amount of fertilizer applied [15]. In the study of threshold effect, it is used as a control variable.

2.2.3. Control variables

(1) Consumer price index of rural residents (CPI)

The rise in the consumer price index of rural residents will inevitably lead to an increase in rural household living expenses, under the premise of the existing arable land area remains unchanged, the farming households can only increase the input of fertilizers and other factors of production in order to increase crop yields, and thus increase the family economic income, which indirectly leads to the aggravation of agricultural surface pollution [28].

(2) Industrial structure (T)

This paper uses the ratio of the secondary industry to the total output value of primary, secondary and tertiary industries. The increase in the proportion of the secondary industry can promote the upgrading of the rural industrial structure, absorb the rural labor force to work in the city, and then increase the overall income of farmers, providing the basis and power for the green development of agriculture [29], and industrial upgrading can improve the ecological environment to a certain extent [30].

(3) Technology level (S)

This paper adopts the proportion of investment in science and technology R&D to regional GDP to measure the technology level of the region [31].

2.2.4. Data sources

The data used in this paper are the panel data of 11 provinces and cities in China's Yangtze River Economic Belt from 2006 to 2021. Among them, the agricultural surface source pollution indicators are from the China Rural Statistical Yearbook. The indicators of environmental regulation are from China Environmental Statistics Yearbook and China Statistical Yearbook. Fertilizer factor market distortion indicators are from the China Statistical Yearbook, provincial and municipal statistical yearbooks, and the National Compendium of Agricultural Product Cost and Benefit Information. Indicators of labor force transfer are from the statistical yearbooks of provinces and cities. Indicators on rural consumer price index, industrial structure and technology level are from China Statistical Yearbook and China Science and Technology Statistical Yearbook. For individual missing observations, linear extrapolation is used to fill in the blanks, and all variables are standardized in this paper before formal regression.

3. Results

3.1. Changes in spatial patterns

3.1.1. Spatial autocorrelation test

In order to test whether there is spatial correlation of agricultural surface source pollution in the Yangtze River Economic Belt, this paper carries out a global spatial autocorrelation test based on geographic neighboring weights for agricultural surface source pollution in the Yangtze River Economic Belt from 2006 to 2021. As shown in Table 1, the global Moran's I indexes of the overall agricultural surface source pollution levels in China's Yangtze River Economic Belt from 2006 to 2020 are all significant at the 10% level, with spatial positive correlations, taking values ranging from 0.15 to 0.45. This indicates that agricultural surface pollution at the provincial and municipal levels in China's Yangtze River Economic Belt presents a certain spatial aggregation phenomenon, and has shown an enhanced trend in recent years.

3.1.2. Subsubsection

Table 1. Global Moran's I Index of Agricultural Surface Source Pollution in Provinces and Municipalities of the Yangtze River Economic Belt, 2006-2020.

Year	I	Year	I

2006	0.431***	2014	0.159*
2007	0.349***	2015	0.155*
2008	0.304**	2016	0.311**
2009	0.271**	2017	0.221**
2010	0.189**	2018	0.243**
2011	0.189**	2019	0.224**
2012	0.158*	2020	0.191*
2013	0.167*	2021	0.380*

Note:*,**and***indicate significance at the 10%,5%,and1%significance levels,respectively.

3.2. Spatial aggregation characteristics

To further examine the spatial aggregation characteristics of agricultural surface source pollution in the Yangtze River Economic Zone, the local Moran's I index was used to test the aggregation of pollution in the provinces and cities of the Yangtze River Economic Zone, and the Moran's scatter plots of agricultural surface source pollution in 2006, 2011, 2016 and 2021 were plotted using ArcGIS10.7 software.

3.3. Subsection

As shown in Figure 2, the local Moran index of agricultural surface pollution in these four years was 0.431, 0.189, 0.311 and 0.038 respectively and all of them were significant, indicating that agricultural surface pollution in each province has strong spatial autocorrelation. In the Moran scatter plot, "H-H" (high-high) and "L-L" (low-low) are located in one or three quadrants, reflecting the positive spatial correlation of environmental pollution; "H-L" (high-low) and "L-H" (high-high) are located in one or three quadrants, reflecting the positive spatial correlation of environmental pollution.) and "L-H" (low-high) are located in quadrants 2 and 4, reflecting the negative spatial correlation of environmental pollution.

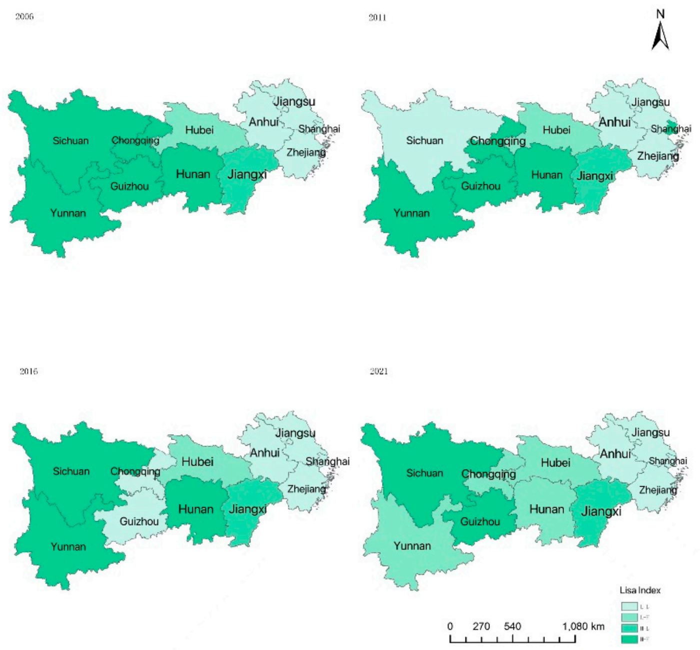

Figure 2. Spatial scattering map of agricultural surface pollution in the Yangtze River Economic Belt region.

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Through the scatter plot of local Moran index, it can be found that the agricultural surface pollution is "H-H" agglomeration pattern, that is, it is a high environmental pollution area surrounded by high environmental pollution provinces at the same time, and their spatial variability is relatively small, mainly including Yunnan, Guizhou, Sichuan, and the western underdeveloped areas where the proportion of primary industry is relatively high. Agricultural surface pollution for the "L-L" agglomeration pattern, that is, their own low environmental pollution areas at the same time surrounded by low environmental pollution provinces, their spatial variability is relatively small, mainly including Jiangsu, Zhejiang, Shanghai and Anhui these tertiary industry accounted for a high proportion of the developed coastal areas. Overall, the above analysis shows that there is a significant positive spatial correlation of agricultural surface pollution in China, and the homogeneous spillover effect of agricultural surface pollution is obvious.

3.3. Analysis of empirical results

The previous analysis shows that there is a spatial aggregation phenomenon of agricultural surface pollution in the Yangtze River Economic Belt in China, thus this paper constructs a spatial Durbin model to further study the specific impacts of environmental regulation, input factor market distortion and labor transfer on agricultural surface pollution.

Before regressing the spatial econometric model, it is tested in four steps [31]. First, the LM test based on OLS estimation of the above models rejected the original hypothesis of "no spatial autocorrelation", indicating that spatial econometric analysis should be conducted. Second, the Hausman test was significant at the 5% level, rejecting the random effect and choosing the fixed effect. Again, the LR and Wald tests significantly rejected the original hypothesis, indicating that the SDM model does not reduce to a spatial error (SEM) model or a spatial lag model (SAR) model. Finally, the above models were estimated using spatial fixed, time fixed and spatio-temporal double fixed effects, respectively. As shown in Table 2, the results show that the SDM model under time fixed effects has a higher degree of fit and the largest R2, which indicates that it is more appropriate to select the time-fixed SDM model. Therefore, this paper selects the spatial Durbin model under time fixed effects for analysis.

Table 2. Estimation results of the spatial Durbin panel regression model.

Variables	Spatial fixed effects		Time fixed effects		Temporal fixed effects	
ER/W×ER	0.035**	-0.089*	-0.268***	0.094	-0.011*	-0.177**
Dis/W×Dis	-0.047	0.428**	2.446***	3.035***	0.005**	0.533***
LM/W×LM	0.226*	-0.194	1.001***	-0.872***	0.058*	-0.320
Lncpi1/W×lncpi1	0.735**	-0.977***	2.168**	1.417	-0.122	-2.974***
S2/W×s2	-0.414***	-0.242*	0.476*	-2.219***	-0.457***	-0.474**
t/W×t	0.099	0.206*	-0.067	1.325***	0.211**	0.676***
ρ	0.269**		-0.534***		-0.155*	
N	176		176		176	
R2	0.5658		0.8141		0.2779	

Note:*,**and***indicate significance at the 10%,5%,and1%significance levels,respectively.

3.3.1. Spatial Durbin Models

The panel spatial econometric models are mainly categorized into three types: SAR, SEM and SDM, and for the consideration of robustness, the estimation results of SAR, SEM and SDM under static time fixed effects are also reported here, as shown in Table 3.

Table 3. Static spatial panel model econometric regression results.

Variables	SDM		SAR	SEM
ER/W×ER	-0.268***	0.094	-0.516***	-0.432**
Dis/W×Dis	2.446***	3.035***	1.622***	1.788***
LM/W×LM	1.001***	-0.872***	0.929***	0.866***
Lncpi1/W×lncpi1	2.168**	1.417	-0.602	0.022
S2/W×s2	0.476*	-2.219***	0.521*	-0.044
t/W×t	-0.067	1.325***	-0.632***	-0.403**
ρ	-0.534***		-0.233***	-0.155
N	176		176	176
R2	0.8141		0.5764	0.5239

Note:*,**and***indicate significance at the 10%,5%,and1%significance levels,respectively.

As can be seen from the regression results in Table 3, the sign of the regression coefficients of the variables in each model and the size of the value are basically consistent, indicating that the results are more robust and more credible, among which the time-fixed spatial Durbin model has the largest decidable coefficient, which indicates that the model chosen in this paper is more reasonable.

Agricultural surface pollution. The coefficient ρ in the spatial Durbin model is significantly negative at the 1% level, which means that agricultural surface pollution between neighboring provinces shows the characteristic of "neighbor as neighbor", that is, local pollution has negative spatial spillover effect on the pollution of neighboring provinces, and the intensification of local pollution will reduce the pollution of neighboring provinces.

The influence of environmental regulation on agricultural surface pollution. The coefficients of environmental regulation in each model are significantly negative, indicating that environmental regulation is an important means of suppressing agricultural surface pollution. This may be due to the fact that when the government increases the amount of investment in environmental protection or the implementation of ecological compensation policy, enterprises will have more funds to improve their production processes, so that it is changed to "environmentally friendly", thereby reducing the emission of pollutants.

The influence of factor market distortion on agricultural surface pollution. The coefficients of factor market distortion in each model are all significantly positive, indicating that the increase of factor market distortion will aggravate agricultural surface pollution. This may be due to the fact that the greater the degree of distortion in the fertilizer market, the greater the circulation of low-priced poor-quality fertilizers in the market, and the massive use of poor-quality fertilizers will further aggravate agricultural surface pollution.

The effect of factor market distortion on agricultural surface pollution in neighboring provinces and cities is further examined. The coefficient of W×Dis in Table 2 is significantly positive, indicating that factor market distortion has a strong spatial spillover effect. With the rapid development of the network, information barriers are broken, and when the fertilizer market in a province is distorted to a great extent, farmers in adjacent provinces are more willing to come to that province to buy low-priced fertilizers, which indirectly exacerbates agricultural surface pollution in adjacent provinces.

The impact of labor transfer on agricultural surface pollution. The coefficients of environmental regulation in each model are significantly negative, indicating that the increase in the proportion of labor force transfer will exacerbate the degree of agricultural surface source pollution. Because with the transfer of rural labor force, in order to make up for the loss of income brought about by this part of the labor force is less, farmers may increase the application of fertilizer, which in turn aggravates the agricultural surface pollution.

Influence of control variables. The regression coefficients of the village consumer price index and industrial structure are both significantly positive, indicating that the rise in the consumer price index of rural residents and the gradual shift of industrial structure to the secondary industry will aggravate agricultural surface pollution to a certain extent.

3.3.2. Effect decomposition measures

Due to the existence of spatial lag terms of variables in the SDM model, the direction and significance of the coefficients of the lag terms are still valid, but the values can not directly reflect the influence of the independent variables on the dependent variable, so it is necessary to further use partial differentiation to decompose the spatial spillover effects into direct effects, indirect effects and total effects. In this paper, the effect decomposition is carried out on the basis of the SDM model, in which the direct effect represents the impact of the environmental regulation intensity, the degree of distortion of the fertilizer factor market and the transfer of labor force on the agricultural surface pollution in the province; and the spatial effect represents the impact of the environmental regulation intensity, the degree of distortion of the fertilizer factor market and the transfer of labor force on agricultural surface pollution in neighboring provinces in the province.

Table 4. Decomposition of spatial effects.

Variables	Decomposition of effect		
	Direct effect	Spatial effect	Total effect
ER	-0.304***	-0.192	0.112
Dis	2.213***	1.415***	3.629***
LM	0.956***	-0.274	1.230***
lncpi	2.153**	0.235	2.388
S2	0.855***	-1.993***	-1.138***
t	-0.261	1.108***	0.847**

Note:*,**and***indicate significance at the 10%,5%,and1%significance levels,respectively.

In the direct effect, the impact of environmental regulation on agricultural surface pollution in the Yangtze River Economic Zone is significantly negative, indicating that the greater the intensity of environmental regulation in the province, the more the situation of agricultural surface pollution can be significantly improved; and the impact of the degree of distortion of the factor market and the transfer of labor in the province is significantly positive, indicating that the reduction of the degree of distortion of the fertilizer factor market and the reduction of the number of labor transfers can effectively reduce the pollution of the agricultural surface sources. In the spatial effect, the degree of factor market distortion has a significant spatial effect on agricultural surface pollution in the Yangtze River Economic Zone, and the spillover effect is obvious; the spatial effect of environmental regulation and labor force transfer is not significant, indicating that it has a smaller impact on agricultural surface pollution in neighboring provinces and cities, and the spillover effect is not obvious. Among the total effects, the degree of factor market distortion and labor transfer have more significant effects on agricultural surface pollution.

3.3.3. Robustness test

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Although the above spatial Durbin model estimation results have shown the effects of environmental regulation, factor market distortion and labor transfer on agricultural surface pollution, in order to make up for the lack of static spatial measurement, and at the same time do the robustness analysis of the previous regression results, the lagged term of agricultural surface pollution is introduced as an explanatory variable, and regression is carried out using the systematic GMM method.

Hausman test showed that fixed effects were better than random effects, and AR (2) greater than 0.1 in autocorrelation test could not reject the original hypothesis that the random perturbation term had no autocorrelation. Sargan in over-identification test is greater than 0.1 and cannot reject the original hypothesis, i.e. all instrumental variables are exogenous and instrumental variables are valid.

From the regression results in Table 5, it can be seen that the effects of L1 and fertilizer factor market distortion on agricultural surface pollution are all positive, and they are all significant at least at the 10% statistical level, indicating that the greater the degree of distortion in the input factor market, the greater the degree of agricultural surface pollution. The effects of environmental regulation and labor transfer on agricultural surface pollution are both negative, and both are significant at least at the 5% statistical level, indicating that increasing the intensity of environmental regulation and increasing the number of labor transfer can significantly reduce agricultural surface pollution. The above results are basically consistent with the regression results of the spatial Durbin model under time fixation, and robustness is tested. Since the coefficients and significance levels of the control variables estimated with the system GMM method are similar to those of the static panel, they are not repeated here .

Table 5. Robustness test.

Variables	Dynamic GMM
L1	0.9747***
ER	-0.0070***
D	0.0178*
LM	0.0052**
CPI	0.6770*
S	0.0056**
T	-0.0385**
AR(1)	-0.92
AR(2)	-0.60
Sargan	138
N	176

Note:*,**and***indicate significance at the 10%,5%,and1%significance levels,respectively.

3.3.4. Threshold effect

(1) Threshold effect

In order to further analyze and study the nonlinear role of factor market distortion on agricultural surface pollution under the role of environmental regulation, this paper draws on Hansen's panel threshold model, adopts environmental regulation as the threshold variable, and incorporates labor transfer into the control variables to carry out the threshold effect test. The results are shown in Figure 6, the test result of single threshold passes the significance test, and the test result of double threshold is not significant, indicating that there is only one threshold value, and the threshold model of factor market distortion and agricultural surface pollution should be set as a single threshold model.

Table 6. Threshold number test and threshold estimation results.

Threshold number	F-statistic	P-value	Critical value			Threshold	95% confidence interval
			1%	5%	10%		
Single Threshold	10.94	0.0167	7.4175	8.8470	12.4979	η_1=0.0873	(0.0861,0.0891)
Double threshold	1.96	0.2867	8.3399	11.1629	17.9211		

(2) Analysis of threshold regression results

Table 7 reports the parameter estimation results of model 7, when environmental regulation is lower than or equal to the first threshold, factor market distortion significantly exacerbates agricultural surface source pollution stock; when environmental regulation is greater than the first threshold, the estimated coefficients decrease. It can be seen that the factor market distortion in the role of environmental regulation on agricultural surface pollution there is a significant nonlinear effect, specifically, factor market distortion on agricultural surface pollution pollution of the pollution increase effect shows a first increase and then decrease in the nonlinear characteristics. The reason may be due to the factor market distortion on agricultural surface source pollution influence path is: the greater its distortion, farmers to save production costs, will increase the use of poor-quality fertilizer, thus exacerbating agricultural surface source pollution. When the intensity of environmental regulation is low, farmers use organic fertilizer and get the compensatory benefit is less than the use of poor-quality fertilizer to save the cost, a large number of farmers will continue to use poor-quality fertilizer, which continues to exacerbate agricultural surface pollution. With the increasing strength of environmental regulation, when it is higher than the first threshold, the compensatory benefits of using organic fertilizer are greater than the cost savings of using poor-quality fertilizer, and more and more farmers will choose to use organic fertilizer instead of poor-quality fertilizer, which slows down the aggravation of agricultural surface pollution to a certain extent.

Table 7. Coefficient estimation results of threshold model and linear model.

Variables	**Estimated value**
D(D⩽0.0873)	0. 3968**(3.97)
D(D > 0.0873)	0.2431*(2.54)
LM	0.1178*(1.85)
CPI	0.2147**(2.60)
S	-0.7304***(-4.50)
T	0.1217**(2.48)
conr	4.8301***(12.32)
R2	0.975

Note:*,**and***indicate significance at the 10%,5%,and1%significance levels,respectively.

4. Conclusions and recommendations

Using the panel data of 11 provinces and cities in the Yangtze River Economic Belt from 2006 to 2021, this paper analyzes the spatio-temporal distribution characteristics of agricultural surface pollution in the Yangtze River Economic Belt under the three perspectives of government, enterprise, and agriculture and their influencing factors using the spatial Durbin model, and conducts a robustness test using the dynamic system GMM method. Based on this, the threshold characteristics of factor market distortion on agricultural surface source pollution under different environmental regulation intensities were further investigated.

Firstly, there is a positive spatial correlation of agricultural surface source pollution in the Yangtze River Economic Zone, and the homogeneous spillover effect is obvious. Among them, the high aggregation area of agricultural surface source pollution is mainly concentrated in the western part of the Yangtze River Economic Belt where the proportion of primary industry is relatively high,

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and the low aggregation area of agricultural surface source pollution is mainly concentrated in the eastern part of the Yangtze River Economic Belt where the proportion of tertiary industry is relatively high.

Then, the analysis of influencing factors shows that the increase of the distortion degree of input factor market will significantly aggravate the agricultural surface pollution in the Yangtze River Economic Belt, while the enhancement of the government's environmental regulation and the increase of the number of rural laborers transferring out of the country will significantly reduce the agricultural surface pollution in the Yangtze River Economic Belt. Among them, the degree of factor market distortion has a significant spatial spillover effect on agricultural surface pollution in the Yangtze River Economic Zone, i.e., an increase in the degree of factor market distortion will not only aggravate the agricultural surface pollution in the province and city, but also worsen the degree of agricultural surface pollution in neighboring provinces and cities.

In addition, further research shows that factor market distortion on agricultural surface pollution has a significant single threshold effect of environmental regulation, and there are significant differences in the impact of factor market distortion on agricultural surface pollution under different environmental regulations. When environmental regulation is lower than or equal to the first threshold, factor market distortion will significantly exacerbate agricultural surface pollution: when it is greater than this value, factor market distortion will still exacerbate agricultural surface pollution, but the impact effect is weakened, and the overall non-linear characteristics of the first increase and then decrease.

Based on the findings of this paper, the following policy recommendations are proposed:

First, from the perspective of coordinated regional development of the Yangtze River Economic Belt, due to the tendency of spatial agglomeration of agricultural surface pollution, the mutual influence between different provinces and municipalities has become an important factor in determining the level of regional agricultural surface pollution. Provincial and municipal governments in the Yangtze River Economic Belt region should strengthen the linkage and establish a sound system of common governance, not only to formulate feasible governance programs in their own provinces and municipalities according to local conditions, but also to pay attention to the governance links with their neighboring provinces and municipalities. Especially in the western provinces and municipalities where high pollution is concentrated, they should break the original "who pollutes, who governs" mode and explore their own common governance system.

Second, when the government formulates environmental regulations, it can appropriately increase the strength of its regulations and continuously improve the applicability and feasibility of the policy. At the same time, should pay attention to environmental regulation and other policies to coordinate the operation, such as with the market mechanism to match the degree of perfection, to find the maximum extent of agricultural pollution can alleviate the degree of surface pollution of the "first threshold value". In addition, should also balance the rewards, such as the government in the formulation of punitive laws and regulations at the same time, but also should continue to improve the agricultural ecological protection compensation system, in the system level design of ecological compensation mechanism, fertilizer reduction, soil transformation and the use of green production technology farmers to implement ecological compensation incentives.

Third, the factor allocation of agricultural resources should adhere to the market-oriented, and constantly improve the market mechanism. Through the construction of state and social co-management and common governance model, it can realize the effective supervision of green agricultural production and sales of various links. Taking the fertilizer factor market as an example, the government can limit the minimum or maximum price of fertilizer, and achieve the balance of supply and demand in the fertilizer market by giving tax incentives or subsidies, so as to reduce the circulation of low-quality fertilizers, and reduce the intensity of fertilizer application to a certain extent.

Fourth, manpower is a powerful guarantee to promote rural revitalization. If the country wants to strengthen agriculture and promote agriculture, it should pay attention to the cultivation of talents. Therefore, local governments should actively implement relevant policies to attract and cultivate a number of high-quality farmers. In terms of policy, optimize rural policies to attract urban migrant workers and unemployed college students to return to their hometowns to start their own businesses; in terms of education, cultivate agricultural professionals, while strengthening the teaching of the idea of sustainable development of agriculture; in terms of industry, follow the footsteps of the Internet era to achieve the development of industrial wisdom, promote the progress of human resources, and create a group of cultured, skilled, understanding of the treatment of pollution, and good at the treatment of pollution. The "three farmers" team.

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