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Environmental Regulation, Urban-Rural Income Gap and Agricultural Green Total Factor Productivity

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Abstract: Environmental regulation is the basis for achieving green agricultural development, and urban-rural integration is the key to optimizing the allocation of agricultural elements and achieving sustainable agricultural development. This paper aims to investigate the spatial spillover effect of environmental regulation on China's agricultural green total factor productivity (AGTFP) and examine the mediating effect of the urban-rural income gap. Both the Super-SBM-DEA model and the Global Malmquist–Luenberger productivity index are used to account for the AGTFP of China's 30 provinces, and the spatial Durbin model and the mediating effect model are used to analyze the impact of environmental regulation. We found that firstly, during the sample period, China's AGTFP has increased with an average annual growth rate of 3.27%, which is mainly promoted by agricultural green technology progress (AGTC). Secondly, both the direct and spatial effects of environmental regulation on AGTFP show a significant "U"-shaped feature and have regional heterogeneity based on differences in economic development levels and factor endowments. Thirdly, there is an "inverted U"-shaped relationship between environmental regulation and the urban-rural income gap, and the urban-rural income gap negatively affects AGTFP. Based on the empirical results, we propose that the Chinese government should pay attention to green technology innovation, break the market segmentation, promote urban-rural integration, and then promote the AGTFP.

Keywords: environmental regulation; agricultural green total factor productivity; urban-rural income gap; nonlinear spatial Durbin model

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1. Introduction

Since the Declaration on the Human Environment was put forward by the United Nations in 1972 [1], most countries in the world have begun to pay general attention to agricultural pollution. Because it is not only related to the sustainable development of agriculture but also determines the well-being of social residents. Especially in developing countries, conventional high-input and low-efficiency agricultural production has damaged the agricultural environment [2], and the environmental pollution caused by this production mode is also a danger to the health of rural residents [3]. As early as 2006, China became the world's largest carbon emitter [4]. Based on the reality of the overuse of agricultural production factors and agricultural environmental pollution, conventional agricultural productivity (ATFP) cannot accurately measure agricultural production performance [5]. Therefore, scholars add resources and environmental factors into the calculation of ATFP, which is called agricultural green total factor productivity (AGTFP) [6]. AGTFP takes into account both agricultural economic output level and dynamic changes of the agricultural production environment and has become the most commonly used indicator to measure green agricultural development.

Among factors that affect AGTFP, environmental regulation is undoubtedly the policy means most valued by government and academia. The realization of green agricultural development in China largely depends on the system and effective implementation of environmental regulation. It can directly affect AGTFP by solving the overuse of factors and environmental pollution externalities [7]. As early as 1992, the Chinese government set sustainable development as a national development strategy. Since 2000, laws and regulations on agricultural pollution prevention and control have increased, and as of 2019, the number of documents involved in the regulation of agriculture environment policy has risen to 122, including the Air Pollution Prevention and Control Law, Cleaner Production Promotion Act and so on. These policies have made important regulations on crop straw burning, reduction in the use of agricultural chemical production factors, irrigation water resources and cultivated land protection, etc., and strictly control the increased application of chemical fertilizers and pesticides, which greatly improves the agricultural production environment and has a positive impact on the well-being of rural residents. However, it should be noted that as a developing country with a large population, China ensures its agricultural sector can meet the production and living needs of its residents while reducing agricultural input such as fertilizers and pesticides. Therefore, it is crucial to explore whether environmental regulation can produce an innovation compensation effect in agriculture. Previous literature has illustrated research outcomes on AGTFP from the aspects of technical efficiency [8], scientific and technological progress [9,10] and agricultural carbon emissions [11]. However, few studies studied the impact of environmental regulation on AGTFP and the spatial spillover effect of environmental regulation. Meanwhile, as an important embodiment of the income distribution effect on environmental regulation, the urban-rural income gap is a key variable representing the coordinated development of the national economy. Environmental regulation can have an important impact on the urban-rural income gap through the industry cost effect and the technological innovation effect. The urban-rural income gap can also significantly change AGTFP through the knowledge spillover effect and pollution shelter effect. Existing research fails to integrate environmental regulation, the urban-rural income gap and AGTFP into a unified research framework. What is the spatial spillover effect of environmental regulation on AGTFP? What is the role of the urban-rural income gap among them? These are problems that need to be solved in this study.

Scholars have different views on the impact of environmental regulation on AGTFP, which can be roughly summarized as follows. The first view adheres to the environmental regulation inhibition theory, believing that environmental regulation will increase the related costs of agricultural production in the short term and hinder the growth of AGTFP [12,13]. The second view adheres to the environmental regulation promotion theory, which holds that environmental regulation can force agricultural producers to innovate and apply green technologies, offset agricultural production costs, and promote agricultural technological progress and AGTFP [14,15]. The third view holds that environmental regulation will inhibit the growth of AGTFP in the short term, but in the long run, the innovative effect of environmental regulation may offset part of the production cost, thereby weakening the inhibitory effect of environmental regulation on AGTFP, even positively promoting AGTFP [16], that is, there is a nonlinear relationship between environmental regulation and AGTFP [17]. Some scholars also studied the impact of environmental regulation on green total factor productivity from a spatial perspective and pointed out that environmental regulation has a positive direct and indirect impact on green total factor productivity [18].

Environmental regulation also indirectly affects AGTFP through the urban-rural income gap. On the one hand, the environmental regulation will increase agricultural production costs, reduce the income of agricultural producers, and expand the urban-rural income gap [19]; on the other hand, environmental regulation will also prompt agricultural producers to adopt green production technologies and increase the added value of agricultural products and the income of agricultural producers, thereby narrowing the urban-rural gap [20]. At the same time, the urban-rural income gap also has an important impact on AGTFP [21,22]. On the one hand, the expansion of the urban-rural income gap means that wages in non-agricultural industries will increase, which will attract some laborers to transfer to urban non-agricultural industries [23], reducing the number of agricultural producers, leading to the abandonment of agricultural land, and reducing the agricultural production and AGTFP. On the other hand, the expansion of the urban-rural income gap will also increase the cost of agricultural producers using chemical fertilizers, pesticides and agricultural film, making agricultural producers reduce the input of agricultural factors and the output of agricultural products and inhibit AGTFP. Contrarily, the narrowing of the urban-rural income gap means that the wages of non-agricultural industries and agricultural industries are approaching, which will make some agricultural producers stay in the agricultural sector, reducing the production cost of agricultural input factors, increasing the total agricultural output value and then improving the AGTFP [24].

Comparing current studies on environmental regulation, urban-rural income gap and AGTFP, we found that there are two concerns that need to be addressed. Firstly, most of the existing studies are carried out under the assumption of individual independence, but in fact, environmental regulation will affect AGTFP in surrounding areas through the knowledge spillover and pollution shelter effects. Secondly, the existing literature fails to consider the possible mediating effect of the urban-rural income gap between environmental regulation and AGTFP. Therefore, we attempt to fill in the gaps in the existing research by focusing on the following three issues. First, we add resource and environmental factors to the conventional ATFP calculation in order to truly reflect China's AGTFP. Second, we distinguish the short-term and long-term impacts of environmental regulation on AGTFP and its regional heterogeneity. We aim to provide a reference for the formulation of reasonable environmental regulation in various regions so as to maximize the level of regional social well-being. Last, we analyze the moderating effect of the urban-rural income gap between environmental regulation and AGTFP, filling the gap that the existing research does not consider the income distribution effect of environmental regulation. To answer these questions, this study adopts the SBM super-efficiency model and the GML index [25] to measure China's AGTFP and frames an empirical nonlinear spatial Durbin model and a mediation effect model based on China's provincial panel dataset from 2001 to 2020 to estimate the impacts. The results show that there is a "U"-shaped relationship between environmental regulation and AGTFP, and the urban-rural income gap has a mediating effect. Specifically, in the short run, environmental regulation will inhibit AGTFP and worsen the urban-rural income gap, while in the long run, environmental regulation can promote AGTFP and inhibit the expansion of the urban-rural income gap. This evidence not only provides a reference for the sustainable development of agriculture but also has important significance for the coordinated development of the national economy and the welfare of human society.

2. Theoretical Mechanism

2.1. Mechanism Analysis of Direct Influence of Environmental Regulation on AGTFP

As an important means for the government to solve the market failure of environmental problems, environmental regulation directly affects AGTFP mainly through the following cost effect and the innovation compensation effect [26]. Scholars who insist on the following cost effect emphasize the inclination of production resources to the field of pollution control and believe that this behavior will squeeze agricultural producers' investment in production technology R & D and agricultural reproduction [27], reducing AGTC and agricultural GDP growth and thus inhibiting the increase in rural residents' income level and AGTFP [28]. This is not conducive to the sustainable development of agriculture and the improvement of rural residents' well-being. However, scholars who insist on the innovation compensation effect argue that environmental regulation increases the cost of agricultural production, which can force agricultural producers to carry out green production technology R & D or adopt green production technology [29], thereby stimulating agricultural producers to technology innovation [30], and increasing the added value of agricultural products to expand the production profits. This can partly or even fully offset the negative impact of the following cost effect and finally improve AGTFP [31].

In the early stage of the environmental regulation, due to a lack of coping capabilities, some producers will increase investment in pollution control to meet regulatory requirements. This will increase agricultural green production costs and crowd out the investment in R & D and application of green production technology, thereby reducing the income level of farmers, inhibiting the AGTFP [32], and reducing the well-being of rural residents; with the continuous increase in environmental regulation intensity and gradual improvement of policies, agricultural producers will respond to the continuous regulation measures by reducing the use of chemical production factors, applying green production factors and adopting green production technology to carry out green production. Although the way increases agricultural green production costs, it will also reduce agricultural pollutant emissions, increase the added value of green agricultural products, and ultimately promote AGTFP [33]. It is beneficial to realize the win-win situation of raising farmers' income and improving the human living environment, and this can effectively improve the welfare level of rural residents. Accordingly, this paper proposes Hypothesis 1:

Hypothesis 1. *The impact of environmental regulation on AGTFP is "U"-shaped.*

The development of modern information technology and transportation facilities makes regions increasingly closely connected. Based on this, the influence of environmental regulation has the characteristics of spatial overflow. However, the public goods attributes of environmental regulation itself determine the differences in local enforcement effects. On the one hand, local government regulation on supervision and execution for the environment is different; the increase in environmental regulation intensity in one region will cause some pollution-intensive industries to shift to the surrounding areas with less environmental regulation intensity [34], resulting in the neighborhood of pollution emissions continuing to increase. This will inhibit the green development of agriculture in surrounding areas; that is, environmental regulation causes the "pollution transfer" effect, which harms the health of residents and reduces the well-being of residents in surrounding areas. On the other hand, the implementation of reasonable environmental policies can encourage agricultural producers to innovate and apply green production technology [35]. Along with the technology demonstration effect, the progress of agricultural green production technology in a region will promote AGTC in surrounding areas through knowledge spillover [36], thus improving AGTFP in adjacent areas, and accelerating the realization of sustainable agricultural development goals and the improvement of the level of well-being of the surrounding area. To sum up, the environmental regulation of a region will not only affect local AGTFP, but also affect the AGTFP of surrounding areas through the pollution transfer effect and the knowledge spillover effect. Generally speaking, in the early stage of environmental policy implementation, local government supervision varies greatly, and pollution transfer is prone to occur, which will inhibit AGTFP and worsen the social welfare level enjoyed by residents in surrounding areas; as government supervision policies are gradually improved, environmental regulation will promote local AGTC and then produce a knowledge spillover effect on agricultural production in surrounding areas, achieving a win-win situation of improving AGTFP and social welfare level. Accordingly, this paper proposes Hypothesis 2:

Hypothesis 2. *The impact of environmental regulation on AGTFP is a "U"-shaped spatial spillover effect.*

2.2. Analysis of the Mediating Effect of Urban-Rural Income Gap between Environmental Regulation and AGTFP

Environmental regulation not only directly affects AGTFP but also indirectly impacts AGTFP through the urban-rural income gap.

On the one hand, environmental regulation will increase regulation costs and reduce employment [37], which will squeeze some production inputs and reduce the profits of agricultural production. As the rural labor force is mainly engaged in agricultural production, it will make some elderly population or rural laborers with lower production skills face the threat of unemployment [38]. For the employment and income level of the urban high-quality labor force, environmental regulation has not lowered their wage level, which will further widen the urban-rural income gap and attract more rural labor force to transfer to cities, leading to the abandonment of land, resulting in the hollowing out of the agricultural industry and the decline of the agricultural output value. That is to say, when society's main goal is raising income, environmental regulation will expand the urban-rural income gap, reduce AGTFP, and hinder the coordinated development of the national economy and the improvement of human social welfare.

However, on the other hand, environmental regulation will enhance the competitiveness of the agricultural production sector [39]. Namely, with the deepening of environmental regulation and the increase in consumer demand for green agricultural products, agricultural producers will upgrade their technology to produce greener products. The higher added value of green agricultural products will increase the profits of agricultural producers and encourage them to expand their production scale, which will increase the income of agricultural labor and narrow the urban-rural income gap [40]. The narrowing of the income gap can accelerate AGTC and further improve AGTFP by optimizing the allocation of urban and rural resources. That is, in the process of urban-rural integration, rural labor can flow freely under the regulation of market mechanism, promoting the rational allocation of labor elements; it will reduce urban labor costs, accelerate the formation of urban economies of scale and external economies, and then reduce the production costs of agricultural green input elements such as agricultural machinery, green fertilizers, and biological pesticides. In other words, when society takes sustainable agricultural development as the goal, environmental regulation will narrow the urban-rural income gap, improve AGTFP, and ultimately achieve a win-win situation of increasing farmers' income and coordinated development between urban and rural areas, thus improving the overall well-being of human society. Accordingly, this paper proposes Hypothesis 3:

Hypothesis 3. *Environmental regulation can affect AGTFP through the urban-rural income gap.*

3. Models, Methods and Data

3.1. Spatial Econometric Model Framing

Theoretical analysis shows that environmental regulation will not only affect local AGTFP but also affect the AGTFP of surrounding areas through spatial spillover effects. Combining the results of LM (lag, error) test, LR (lag, error) test and the Hausman test (the LM-lag value is 178.689 *** (p = 0.000), which significantly rejects the null hypothesis, indicating that the spatial lag model is better; the value of LM-error is 182.986 *** (p = 0.000), indicating that the spatial error model outperforms the OLS model. The values of LR_Spatial_lag and LR_Spatial_error are 14.77 ** (p = 0.0390) and 14.78 ** (p = 0.0389), respectively, both of which significantly reject the null hypothesis at the 5% level, indicating that the spatial Durbin model is more suitable for the selection of the model in this study. At the same time, the Hausman value of 37.57 *** (p = 0.000) significantly rejected the null hypothesis, indicating that fixed effects should be added to the article model), it can be seen that the fixed-effect spatial Durbin model is more suitable for the selection of the article model. At the same time, considering the possible nonlinear characteristics between environmental regulation and AGTFP, this paper selects the nonlinear spatial Durbin model (SDM) as the benchmark regression model for analysis. The advantage of the spatial Durbin model is that no matter whether the real data generation process is a spatial lag model or a spatial error model, an unbiased estimate of the coefficients can be obtained based on this model. At the same time, it does not impose any pre-limits on the size of the spillover effect in the latent space, which also makes the model and its estimation of the spillover effect more general [41]. The model is constructed as follows:

$$\begin{aligned} GTFP_{it} = \alpha_1 ENV_{it}{}^2 + \alpha_2 ENV_{it} + \alpha_3 W_{ij}\cdot ENV_{it}{}^2 + \alpha_4 W_{ij}\cdot ENV_{it} + \alpha_5 X_{it} + \alpha_6 W_{ij} \\ \cdot X_{it} + \mu_i + \lambda_i + \varepsilon_{it} \end{aligned} \tag{1}$$

Among them, i and t denote the region and year, respectively; $GTFP_{it}$ denotes the agricultural green total factor productivity; ENV_{it} denotes the intensity of environmental regulation; X_{it} denotes the control variables; W_{ij} is the spatial weight matrix; μ_i and λ_i denote the regional fixed effect and the time fixed effect, respectively; and ε_{it} is the random disturbance term.

In addition, in order to test the mediating effect of the urban-rural income gap between environmental regulation and AGTFP, this paper follows the mediating effect model (Wu et al., 2021) [42] to construct a recursive model consistent with the previous benchmark model to identify the transmission mechanism.

$$\begin{aligned} THEIL_{it} = \beta_1 ENV_{it} + \beta_2 ENV_{it}{}^2 + \beta_3 W_{ij}\cdot THEIL_{it} + \beta_4 W_{ij}\cdot ENV_{it} + \beta_5 W_{ij} \\ \cdot ENV_{it}{}^2 + \beta_6 X_{it} + \beta_7 W_{ij}\cdot X_{it} + \mu_i + \lambda_i + \varepsilon_{it} \end{aligned} \tag{2}$$

$$\begin{aligned} GTFP_{it} = \gamma_1 ENV_{it} + \gamma_2 ENV_{it}{}^2 + \gamma_3 THEIL_{it} + \gamma_4 W_{ij}\cdot GTFP_{it} + \gamma_4 W_{ij}\cdot ENV_{it} \\ + \gamma_4 W_{ij}\cdot ENV_{it}{}^2 + \gamma_4 W_{ij}\cdot THEIL_{it} + \gamma_4 X_{it} + \gamma_4 W_{ij}\cdot X_{it} \\ + \mu_i + \lambda_i + \varepsilon_{it} \end{aligned} \tag{3}$$

Among them, i is the region; t is the year; $THEIL_{it}$ is the urban-rural income gap, and the other variables are the same as above.

3.2. Spatial Autocorrelation Test Model

Before applying the spatial econometric model regression, it is necessary to consider whether there is a spatial correlation between variables. Referring to Yang et al. (2021) [43], we use the global Moran's I index to test the spatial autocorrelation of AGTFP and environmental regulation (ENV). The calculation method is as follows:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - \bar{x})(x_j - \bar{x})}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \tag{4}$$

Among them, I is the global Moran value; S^2 is the sample variance; W_{ij} is the element of the spatial weight matrix; x_i is the AGTFP or environmental regulation in the i region; and $\bar{x}$ is the sample mean. The value range of the global Moran value is $[-1, 1]$. When $I > 0$, there is a positive correlation; when $I < 0$, there is a negative correlation; and when I approaches 0, there is no space correlation.

3.3. Variable Definitions and Data Sources

3.3.1. Variable Definitions

- Explained variable

The explained variable in this paper is the agricultural green total factor productivity (AGTFP). Since the DEA model has non-angular and non-radial features and the ML index has difficulties in solving the problem of infeasible solutions for linear programming, this paper mainly refers to Tone (2003) [25] and uses the SBM super-efficiency model and GML index to measure the AGTFP of 30 provinces in China from 2001 to 2020. The specific calculation process is as follows:

The efficiency value of K decision unit (j = 1, 2, ... n) is:

$$\min\rho = \frac{1 + \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{ik}}}{1 - \frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{rk}{}^g} + \sum_{t=1}^{s_2}\frac{s_t^b}{y_{tk}{}^b}\right)} \tag{5}$$

$$\text{s.t.} \sum_{j=1,j\neq k}^{n} x_{ij}\lambda_j - s_i^- \leq x_{ik} \tag{6}$$

$$\sum_{j=1,j\neq k}^{n} y_{rj}\lambda_j + s_r^g \geq y_{rk}^g \tag{7}$$

$$\sum_{j=1,j\neq k}^{n} y_{tj}\lambda_j - s_t^b \leq y_{tk}^b \tag{8}$$

$$\lambda \geq 0, s^g \geq 0, s^b \geq 0, s^- \geq 0$$

The GML index construction based on the output angle is as follows:

$$GML^{t,t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}; x^t, y^t, b^t\right) = \frac{1 + D_G^T(x^t, y^t, b^t)}{1 + D_G^T\left(x^{t+1}, y^{t+1}, b^{t+1}\right)} \tag{9}$$

$$GML^{t,t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}; x^t, y^t, b^t\right) = \frac{TE^{t+1}}{TE^t} \times \frac{BPG_{t+1}^{t,t+1}}{BPG_t^{t,t+1}} = GEC^{t,t+1} \times GTC^{t,t+1} \tag{10}$$

Among them, (x^t, y^t) is the input-output combination in period t; y^g is the expected output; y^b is the undesired output; the vector λ is the weight; s is the slack variable; $\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{X_{ik}}$ and $\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{rk}{}^g} + \sum_{t=1}^{s_2}\frac{s_t^b}{y_{tk}{}^b}\right)$ are the average inefficiencies of the input and output, respectively; and $GML^{t,t+1}$, $GEC^{t,t+1}$, and $GTC^{t,t+1}$ denote changes in agricultural green total factor productivity, green technology efficiency, and green technology progress from period t to period t + 1, respectively. The input indicators in this paper are land, labor, draft animals, mechanical power, irrigation, pesticides, agricultural film and chemical fertilizers [44]. The specific measurement method mainly refers to IPCC (2007) [45]. We use the expected agricultural output and undesired agricultural output as output indicators. We choose agricultural gross output value as the proxy index of agricultural expected output [46]. The proxy index fully reflects the income level of farmers and can have a direct impact on the well-being of agricultural producers. At the same time, this paper deflates the proxy index to eliminate the impact of price factors. For undesired agricultural output, we select the agricultural comprehensive pollution index [11] and agricultural carbon emissions [8]. These two proxies have a significant impact on the sustainable development of agriculture, the health status of residents and the living environment of rural residents. Among them, the comprehensive agricultural pollution index is processed by entropy weight, including chemical oxygen demand, total nitrogen and phosphorus loss, carbon dioxide emissions, soil pesticides and agricultural film residues, etc. The specific indicators are shown in Table 1.

At the same time, in order to reflect the cumulative change trend of China's AGTFP, this paper transforms the measured AGTFP into a fixed-base index. Let the Chinese AGTFP in 2000 be 1; the actual value of the Chinese AGTFP in 2001 is the product of the Chinese AGTFP in the current year and the Chinese AGTFP in 2000, and so on.

Table 1. Specific measurement indicators of AGTFP.

Factors	Indicators	Measurement Methods	Data Sources
Input	Land	Total sown area of crops	"China Rural Statistical Yearbook"
	Labor	Total labor force in plantation industry	"China Statistical Yearbook"
	Draft animals	Number of large livestock	"China Rural Statistical Yearbook"
	Mechanical power	Total power of agricultural machinery	"China Rural Statistical Yearbook"
	Irrigation	Actual effective irrigation area	"China Rural Statistical Yearbook"
	Pesticides	Pesticide usage	"China Rural Statistical Yearbook"
	Agricultural film	Amount of agricultural film used	"China Rural Statistical Yearbook"
	Chemical fertilizers	Fertilizer application scalar: nitrogen, phosphorus, compound fertilizer usage	"China Rural Statistical Yearbook"
Output	Expected output	Real agricultural output	"China Statistical Yearbook"
	Unexpected output	Agricultural comprehensive pollution	"China Rural Statistical Yearbook"
		Agricultural carbon emissions	"China Rural Statistical Yearbook"

Note: The missing value of a small amount of data is measured by linear interpolation method.

- Core explanatory variable

Environmental regulation (ENV) is mainly divided into three categories: command-and-control, market incentive and voluntary environmental regulation. Considering that the goal of agricultural producers is profit maximization, they do not actively take agricultural pollution emissions as their main focus when making production decisions and lack market incentives for agricultural production. Therefore, this paper mainly starts with the command-and-control environmental regulation and examines its influence. Bimonte (2002) [47] found that the area of nature reserves is a direct measure of government environmental expenditure and policies. Therefore, this paper refers to Yang (2019) [48] and selects the proportion of the area of nature reserves to the sown area of crops as a proxy variable for environmental regulation.

- Mediating variable

The urban-rural income gap (THEIL) is an important variable that affects the relationship between environmental regulation and AGTFP. Therefore, this paper uses the ratio of urban per capita disposable income to rural per capita net income as a proxy variable for the urban-rural income gap [49] and selects the Theil index [50] (theil) as its replacement variable for robustness testing. The specific calculation formula of theil is:

$$\mathrm{theil}_{i,t} = \sum_{j=1}^{2} \left(\frac{P_{ij,t}}{P_{i,t}} \right) \ln \left(\frac{P_{ij,t}}{P_{i,t}} / \frac{Z_{ij,t}}{Z_{i,t}} \right) \tag{11}$$

Among them, $j = 1$ is urban; $j = 2$ is rural; P is disposable income; and Z is the number of residents.

- Control variable

Regarding industrial structure (INS), the improvement of the agricultural industrial structure is conducive to optimizing factor allocation, thereby promoting AGTFP and the well-being level of agricultural producers. This paper selects the proportion of the added value of the crop industry in the added value of agriculture, forestry, animal husbandry and fishery as a proxy variable of the industrial structure.

Regarding the degree of disaster (ADR), the more serious the disaster, the greater the economic loss of farmers, the damage to the production environment and the obstacles to AGTFP, which will reduce the well-being of agricultural producers. This paper characterizes it by the proportion of the affected area in the total sown area of crops.

Regarding agricultural machinery density (MAC), the increase in agricultural machinery density is conducive to improving agricultural technical efficiency but may increase greenhouse gas emissions, and its impact on the well-being of agricultural producers is uncertain. This paper selects the ratio of the total power of agricultural machinery to the total sown area as a proxy variable for agricultural machinery density.

Regarding the educational level of the labor force (EDU), the higher the education level of the labor force, the higher the level of production skills, which is conducive to the reduction of agricultural pollution emissions, the improvement of AGTFP and the well-being of agricultural producers. This paper uses the average years of education of the labor force to characterize this variable [51].

Regarding trade dependency (TRA), the increase in trade dependence will increase the revenue of agricultural producers, thus promoting AGTFP and agricultural sector well-being [52]. This paper uses the ratio of the total import and export of regional agricultural products to the total agricultural production to characterize this variable. Descriptive statistics of each variable are shown in Table 2:

Table 2. Variable descriptive statistics.

Variable Name	Code	N	Mean	Sd	Min	Max
Agricultural green total factor productivity	AGTFP	600	1.4937	0.7087	0.3776	4.5152
Agricultural green technology progress	AGTC	600	1.6814	1.1513	0.4449	11.0719
Agricultural green technology efficiency	AGEC	600	0.9979	0.3356	0.0862	2.2768
Environmental regulation	ENV	600	0.1963	0.7239	0.0016	4.4147
Urban-rural income gap	THEIL	600	2.8513	0.5712	1.8500	5.1200
Theil index	theil	600	0.1162	0.0577	0.0183	0.3198
Industrial structure	INS	600	0.5234	0.0870	0.3378	0.7458
The degree of disaster	ADR	600	0.2221	0.1561	0.0000	0.9308
Agricultural machinery density	MAC	600	0.5638	0.2642	0.1393	1.4155
Educational level of labor force	EDU	600	7.2405	1.4924	0.7018	9.8380
Trade dependency	TRA	600	0.3018	0.3665	0.0163	1.6956

3.3.2. Data Sources

This paper selects relevant data from 30 provinces, municipalities and regions in China for research. At the same time, since China paid more attention to agricultural green production behavior after 2000 [53], the final time span of the article is 2001–2020. Among them, the AGTFP data are mainly calculated by the author. Data on environmental regulation, Theil index and agricultural industry structure are mainly from the 2002–2021 *China Statistical Yearbook* (China Statistical Yearbook: http://www.stats.gov.cn/tjsj/ndsj/ (accessed on 1 June 2022)). The data on the degree of disaster and the density of agricultural machinery are mainly from the *China Rural Statistical Yearbook* (China Rural Statistical Yearbook: https://www.yearbookchina.com/naviBooklist-YMCTJ-0.html (accessed on 1 June 2022)) from 2002 to 2021. The data on the education level of the labor force mainly comes from the *China Population and Employment Statistical Yearbook* (China Population and Employment Statistical Yearbook: https://www.yearbookchina.com/navibooklist-n3022013208-1.html (accessed on 1 June 2022)) from 2002 to 2021. The trade dependence data mainly comes from the 2002–2021 *China Agricultural Yearbook* (China Agricultural Yearbook: https://data.cnki.net/yearbook/Single/N2022030154 (accessed on 1 June 2022)) and the *China Agricultural Products Trade Development Report*.

4. Results Analysis and Discussion

4.1. Analysis of Statistical Results

4.1.1. Calculation Results of AGTFP

Based on the input-output data of 30 provinces in China from 2001 to 2020, this paper uses the SBM super-efficiency model and the GML index to calculate China's AGTFP (Table 3). Overall, the national average AGTFP from 2001 to 2020 showed a significant time sequence, with an average annual growth rate of 3.27%, indicating that the well-being in China's agricultural sector was continuously improving AGTFP and agricultural green technology progress (AGTC) basically maintained the same growth rate, while the agricultural green technology efficiency (AGEC) remained at a low level. China's AGTFP has great potential to be improved through AGEC [54]. In terms of stages, during 2001–2005, China's AGTFP grew slowly, mainly because China's agricultural production was greatly affected by natural disasters such as droughts, floods and waterlogging during the "Tenth Five-Year Plan" period, which hindered AGTC and slowed down the improvement of agricultural producers' well-being. From 2005 to 2010, AGTFP increased gradually with an average annual growth rate of 8.55%. This is because China's fiscal support for agriculture gradually increased after 2004, and the abolition of agricultural taxes and other policies has greatly improved agricultural technology, thus effectively improving human well-being; However, during 2010–2020, the average annual growth rate of China's AGTFP dropped to 2.78%. Here we can learn from Hazell (2009) [55] that this is because the kinetic energy of AGTFP during this period was mainly driven by AGTC, while producers' investment in AGTC decreased under the constraint of environmental regulation, resulting in insufficient power for agricultural green and intensive growth, so the welfare of the agricultural sector did not improve much.

Table 3. China's AGTFP changes and its decomposition in 2001–2020.

Year	AGTFP	AGEC	AGTC	Year	AGTFP	AGEC	AGTC
2000–2001	0.9752	1.0122	0.9635	2010–2011	1.4848	0.9219	1.6106
2001–2002	0.9406	0.9978	0.9426	2011–2012	1.6253	0.9270	1.7533
2002–2003	0.9437	1.0365	0.9105	2013–2014	1.7550	0.9018	1.9462
2003–2004	0.9965	1.0664	0.9344	2014–2015	1.6830	0.8580	1.9616
2004–2005	1.0108	0.9823	1.0291	2015–2016	1.7593	0.8338	2.1100
2005–2006	0.9965	0.9403	1.0597	2016–2017	1.6011	0.8270	1.9361
2006–2007	1.0784	0.9672	1.1149	2017–2018	1.8400	0.8416	2.1863
2007–2008	1.1523	0.9685	1.1898	2018–2019	2.0378	0.8226	2.4773
2008–2009	1.1871	0.9682	1.2262	2019–2020	1.7956	0.8391	2.1400
2009–2010	1.4035	0.9346	1.5017	2012–2013	1.7209	0.9256	1.8592
Major grain-producing	1.4967	0.9801	1.5271	Non-major grain-producing	1.2514	0.8864	1.4117
Eastern	1.3906	0.9795	1.4197	Central	1.4159	1.0059	1.4076
Western	1.2719	0.8239	1.5437	National	1.3523	0.9259	1.4606

Note: The average value in the table is the geometric mean.

Taking region into account, the average annual growth rate of AGTFP in the western region (3.51%) is higher than in other regions (the eastern region: 3.19%; the central region: 3.03%). The main reason is that the agricultural production mode in the western region is relatively backward, and the eastern and central regions improve the green technology level in the western region through the technological knowledge spillover effect, which is conducive to the rapid growth of AGTFP in the western region. Table 3 shows that the growth rate of AGTC in major grain-producing areas (5.27%) is significantly higher than that in non-major grain-producing areas (4.12%). This is because the resource endowment conditions of major grain-producing areas have significant advantages, which can form a large-scale production model of the agricultural industry. This is conducive to optimizing factor allocation, reducing pollution emissions, promoting green technology progress, and thus, improving the well-being of agricultural production in the region.

4.1.2. Spatial Autocorrelation Test Results

Table 4 shows the Moran index and significance test results of AGTFP and environmental regulation in 30 of China's provinces from 2001 to 2020. The Moran index values of environmental regulation are significantly positive at the level of 5%, indicating that there is a significant positive spatial correlation between provincial environmental regulation. The global Moran index for 2001–2020 passed the significance test for most of the years 2001–2016, but failed for 2017–2020. The progress rate of AGTC slowed down during this period, resulting in insufficient power for agricultural green and intensive growth, and the regional correlation of AGTFP was mainly realized through the spillover effect of knowledge and technology, which led to the weakening of the spatial correlation in this period. The Moran index values in other years were all significantly positive, indicating that China's AGTFP has a strong spatial correlation on the whole.

Table 4. Moran's I value of AGTFP and environmental regulation from 2001 to 2020.

Year	AGTFP	ENV	Year	AGTFP	ENV
2001	0.151 *	0.119 ***	2011	0.198 **	0.075 ***
2002	0.367 ***	0.107 ***	2012	0.172 **	0.074 ***
2003	0.027	0.102 ***	2013	0.176 **	0.065 ***
2004	0.127 *	0.101 ***	2014	0.147 **	0.066 ***
2005	−0.049	0.100 ***	2015	0.191 **	0.063 ***
2006	0.193 **	0.096 ***	2016	0.163 **	0.062 ***
2007	0.264 ***	0.093 ***	2017	0.119	0.062 ***
2008	0.212 ***	0.079 ***	2018	0.090	0.059 ***
2009	0.197 ***	0.075 **	2019	0.045	0.035 ***
2010	0.154 **	0.080 ***	2020	0.035	0.034 ***

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.2. Benchmark Regression Results and Discussion

4.2.1. Spatial Durbin Model Test and Results Estimation

The common spatial weight matrix is mainly a 0–1 matrix, but this matrix type ignores the correlation of environmental regulation between non-adjacent regions. Therefore, according to the first law of geography that the correlation between things is related to geographical distance [56], this paper carried out the fixed-effect spatial Dubin model regression based on the inverse geographical distance square weighted matrix. On this basis, the above regression is repeated using the spatial lag model (SAR) and the spatial error model (SEM), and the results are shown in Table 5.

It can be seen that the primary term coefficient of environmental regulation is significantly negative, and the quadratic term coefficient is significantly positive, indicating that in the sample period, the impact of environmental regulation on AGTFP is "U"-shaped, and Hypothesis 1 is verified. This is because agricultural producers lack environmental awareness. In the early stage of environmental regulation, agricultural producers will follow the traditional path of dependence; the current mode of production will be maintained by investing more in pollution control costs, which will crowd out part of the green R & D investment, hinder the green upgrading of agricultural production, and is not conducive to the improvement of farmers' income level, the sustainable development of agriculture, and the improvement of the welfare of the agricultural sector. This is consistent with the conclusion of Liang, L (2012) [12]. As the intensity of environmental regulation continues to increase, the cost of agricultural producers to meet the corresponding regulatory standards is higher than the expected profit. At this time, some agricultural producers will ensure household income through non-agricultural transfer, which will reduce labor input and agricultural production value of the agricultural sector, thereby inhibiting AGTFP. However, in the long term, agricultural producers' awareness of environmental protection and green production will continue to increase, and they will choose to adopt green production technology, optimize factor allocation and clean factor use, etc. [15]. This can not only reduce pollution emissions and improve the living environment of residents but also increase agricultural profits, thus improving AGTFP and the well-being of agricultural producers.

Table 5. Spatial Durbin model test and results estimation.

Variable	SDM		SEM		SAR	
	FE	RE	FE	RE	FE	RE
ENV^2	0.1682 *** (0.0572)	0.2780 *** (0.0744)	0.1823 *** (0.0585)	0.2817 *** (0.0690)	0.2012 *** (0.0540)	0.2849 *** (0.0737)
ENV	−0.6611 *** (0.2399)	−1.0666 *** (0.3224)	−0.7826 *** (0.2431)	−1.1853 *** (0.3016)	−0.8696 *** (0.2203)	−1.1958 *** (0.3165)
INS	3.6478 *** (0.3013)	3.8025 *** (0.4739)	2.6243 *** (0.2785)	3.8110 *** (0.4712)	2.7704 *** (0.2721)	3.3397 *** (0.4234)
ADR	−0.3737 ** (0.1643)	−0.1055 (0.1462)	−0.6161 *** (0.1706)	−0.2760 * (0.1572)	−0.5658 *** (0.1636)	−0.4687 *** (0.1285)
MAC	0.4731 *** (0.1233)	0.6215 *** (0.1564)	0.3162 *** (0.0951)	0.6057 *** (0.1598)	0.2910 *** (0.0880)	0.8449 *** (0.1381)
EDU	−0.0258 (0.0307)	−0.0138 (0.0255)	0.0296 (0.0196)	−0.0126 (0.0199)	0.0252 (0.0173)	−0.0068 (0.0118)
TRA	0.1322 * (0.0711)	0.2346 * (0.1253)	0.1157 * (0.0669)	0.2810 ** (0.1257)	0.1110 * (0.0647)	0.1068 (0.1137)
W * ENV^2	1.0174 *** (0.1445)	0.1325 (0.1830)				
W * ENV	−4.5301 *** (0.6041)	−0.9271 (0.7805)				
W * INS	0.1230 (0.9317)	−2.4163 *** (0.8398)				
W * ADR	0.0188 (0.3600)	−0.5745 ** (0.2459)				
W * MAC	0.2374 (0.1900)	0.8236 *** (0.2315)				
W * EDU	0.0480 (0.0537)	0.0093 (0.0370)				
W * TRA	−0.5736 *** (0.2054)	−0.8817 *** (0.2419)				
_cons		−0.2488 (0.4459)		−0.6884 ** (0.3394)		−1.4064 *** (0.2723)
Spatial ρ or λ	0.1804 ** (0.0707)	0.4772 *** (0.0515)	0.2381 *** (0.0754)	0.7323 *** (0.0391)	0.3406 *** (0.0640)	0.5997 *** (0.0407)
Within -R^2	0.3986	0.5545	0.3257	0.3207	0.3825	0.5011

Note: * $p < 0.1$ ** $p < 0.05$, *** $p < 0.01$.

The influence coefficient of agricultural structure is significantly positive, indicating that the improvement of agricultural structure will reduce unreasonable consumption, realize the rational allocation of agricultural resources, and thus promote AGTFP. The direct influence coefficient of agricultural disaster degree is significantly negative because agricultural disaster will destroy processes and environment of agricultural production, reduce agricultural production profits, inhibit green R & D investment in agriculture, and negatively affect AGTFP and agricultural well-being. Agricultural machinery density has a positive impact on AGTFP, indicating that the increase of agricultural machinery density will reduce agricultural production costs, increase profits of agricultural producers, facilitate the increase in input in technology R & D and other factors, promote AGTFP and increase welfare in the agricultural sector. The direct influence coefficient of labor education level is negative because the improvement of rural labor education level will lead to the cross-regional and cross-sectoral transfer of labor, which limits labor input in agricultural production, thus inhibiting AGTFP and reducing the welfare of the agricultural sector. Trade dependence has a positive impact on AGTFP because the increase in trade expenditure will increase agricultural production revenue, promote AGTC and AGTFP, and further improve the welfare of the agricultural sector. At the same time, the regression results of the SEM model and the SAR model show that the significance and signs of each explanatory variable are basically the same, indicating that the benchmark regression results have good robustness.

4.2.2. Spatial Durbin Model Effect Decomposition

In order to further determine the spatial spillover effect of environmental regulation on AGTFP, this paper decomposes the total spatial effect of each variable, and the results are shown in Table 6. It can be seen that the direct influence coefficient of the quadratic term of environmental regulation is significantly positive, indicating that the influence of environmental regulation on AGTFP in this region is "U"-shaped. The spatial influence coefficient of the primary term of environmental regulation is significantly negative, and the quadratic term coefficient is significantly positive, indicating that the impact of the local environmental regulation measures on the AGTFP of the surrounding areas is also "U"-shaped. Hypothesis 2 is verified. At the beginning of environmental regulation, the lack of coping ability will lead to the relocation of heavily polluting industries to neighboring areas, thus aggravating the environmental pollution situation in surrounding areas and hindering the growth of AGTFP and agricultural well-being in this area. However, in order to meet the continuous regulatory requirements, agricultural producers will transform and upgrade their production modes through green innovation and other means. At this time, the technological innovation of agricultural production in this region will indirectly promote AGTFP growth in surrounding areas through the knowledge spillover effect, which is conducive to promoting sustainable development of agriculture and the welfare of the agricultural sector.

Table 6. Benchmark regression model effect decomposition.

Variable	SDM-FE			SAR-FE		
	Direct	**Indirect**	**Total**	**Direct**	**Indirect**	**Total**
ENV^2	0.2043 *** (0.0575)	1.2349 *** (0.1594)	1.4392 *** (0.1728)	0.2080 *** (0.0563)	0.0994 *** (0.0338)	0.3074 *** (0.0818)
ENV	−0.8224 *** (0.2402)	−5.4790 *** (0.6753)	−6.3014 *** (0.7069)	−0.8994 *** (0.2299)	−0.4302 *** (0.1412)	−1.3296 *** (0.3338)
INS	3.7050 *** (0.2877)	1.0243 (1.0940)	4.7293 *** (1.1477)	2.8633 *** (0.2659)	1.3936 *** (0.3847)	4.2569 *** (0.5470)
ADR	−0.3755 ** (0.1587)	−0.0775 (0.4258)	−0.4530 (0.4283)	−0.5787 *** (0.1633)	−0.2828 ** (0.1164)	−0.8615 *** (0.2623)
MAC	0.4876 *** (0.1174)	0.3899 * (0.2287)	0.8774 *** (0.2209)	0.3004 *** (0.0863)	0.1446 *** (0.0535)	0.4449 *** (0.1293)
EDU	−0.0227 (0.0293)	0.0484 (0.0539)	0.0257 (0.0380)	0.0266 (0.0175)	0.0130 (0.0096)	0.0396 (0.0264)
TRA	0.1160 (0.0737)	−0.6419 *** (0.2481)	−0.5260 ** (0.2566)	0.1144 * (0.0687)	0.0562 (0.0377)	0.1706 (0.1042)

Note: * $p < 0.1$ ** $p < 0.05$, *** $p < 0.01$.

4.3. Mediation Test

Theoretical analysis shows that environmental regulation can indirectly affect AGTFP by affecting the urban-rural income gap. Therefore, this paper empirically tests this mediating mechanism. The specific testing processes are as follows: The first step is to regress Equation (1) to test whether the quadratic coefficient of environmental regulation is significant. If it is significant, it means that environmental regulation has an impact on AGTFP.

The second step regresses Equation (2), in which the urban-rural income gap is a mediator variable. If environmental regulation and its quadratic coefficient are significant at this time, it means that environmental regulation has an impact on the mediator variable. The third step is to regress Equation (3). If the regression coefficients are all significant, it means that the urban-rural income gap has an impact on the relationship between environmental regulation and AGTFP. The test results are shown in Table 7, where Regression (1)–Regression (3) are the regression results of the mediating effect model, and Regression (4) and (5) are the regression results when the Theil index is used as the replacement variable for the THEIL, it can be seen that the significance of its core explanatory variables is consistent with the test results of the mediation effect model, indicating that the mediation effect model is robust.

Table 7. Mediation test results.

Variable	(1)	(2)	(3)	(4)	(5)
	AGTFP	**THEIL**	**AGTFP**	**Theil**	**AGTFP**
THEIL			−0.2933 *** (0.0637)		−3.5265 *** (0.8424)
ENV^2	0.1682 *** (0.0572)	−0.2218 *** (0.0506)	0.2178 *** (0.0570)	−0.0102 ** (0.0041)	0.2122 *** (0.0570)
ENV	−0.6611 *** (0.2399)	1.0615 *** (0.2096)	−0.8618 *** (0.2391)	0.0536 *** (0.0172)	−0.8461 *** (0.2391)
INS	3.6478 *** (0.3013)	1.8083 *** (0.2200)	3.9759 *** (0.3025)	0.1699 *** (0.0182)	4.0345 *** (0.3073)
ADR	−0.3737 ** (0.1643)	0.2533 ** (0.1186)	−0.3001 * (0.1646)	0.0233 ** (0.0099)	−0.3185 * (0.1651)
MAC	0.4731 *** (0.1233)	−0.0861 (0.0770)	0.4396 *** (0.1210)	−0.0026 (0.0063)	0.4829 *** (0.1214)
EDU	−0.0258 (0.0307)	−0.0642 *** (0.0215)	−0.0402 (0.0302)	−0.0056 *** (0.0017)	−0.0414 (0.0303)
TRA	0.1322 * (0.0711)	−0.0343 (0.0499)	0.0985 (0.0700)	−0.0438 *** (0.0041)	−0.0266 (0.0800)
Spatial ρ	0.1804 ** (0.0707)	0.5384 *** (0.0434)	0.1853 *** (0.0701)	0.6103 *** (0.0416)	0.1808 ** (0.0703)
Within -R^2	0.3986	0.3306	0.4392	0.2940	0.4441

Note: * $p < 0.1$ ** $p < 0.05$, *** $p < 0.01$.

Specifically, Regression (1) shows that environmental regulation and its quadratic coefficient are significantly negative, indicating that there is an inverted U-shaped relationship between environmental regulation and AGTFP. Regression (2) shows that the quadratic coefficient of environmental regulation is significantly negative, indicating that there is also an inverted U-shaped relationship between environmental regulation and the urban-rural income gap. The reason is that the constraints of environmental regulation in the agricultural field will increase the cost of agricultural producers for pollution control, which will reduce the income level of agricultural labor in a short time but have little impact on the income of urban non-agricultural labor. This will gradually increase the urban-rural income gap. In other words, environmental regulation worsens coordinated urban and rural development and hinders the improvement of social well-being; however, in the long run, the deepening environmental regulation will prompt agricultural labor to adopt green production technologies and methods, increase the added value and market price of agricultural products, and increase their income, thus narrowing the income distribution gap. That is, environmental regulation reduces the urban-rural income gap and improves human social well-being. Regression (3) shows that the coefficient of the urban-rural income gap is significantly negative, indicating that environmental regulation can significantly affect

AGTFP through the urban-rural income gap and the impact of the urban-rural income gap on AGTFP is significantly negative. Hypothesis 3 is verified. On the one hand, the widening of the urban-rural income gap will accelerate the non-agricultural transfer of rural labor force, especially the high-quality labor force, resulting in a shortage of agricultural labor factors, thus inhibiting AGTFP. On the other hand, the integration of urban and rural development will optimize the allocation of agricultural production resources and improve the efficiency of factor use, thus achieving a win-win situation of coordinated urban and rural development and AGTFP improvement, effectively improving the overall well-being of society.

4.4. Analysis of Regional Estimation Results

Due to different levels of economic development and factor endowments in different regions, the impact of environmental regulation on AGTFP may also vary. Therefore, this paper further divides 30 provinces in China into major grain-producing areas, non-major grain-producing areas, east, middle and west [57], to further test the possible regional heterogeneity of the impact of environmental regulation on AGTFP, as shown in Table 8.

In the eastern region, environmental regulation negatively affects AGTFP. Agricultural producers have a low adoption of technological innovation, and the cost required by the government to implement environmental regulation occupies resources that could have been used to improve agricultural production conditions, leading to the suppression of AGTFP by environmental regulation, which is not conducive to the sustainable development of agriculture and the improvement of agricultural welfare. In the middle, the squared coefficients of environmental regulation and its lag terms are significantly negative, indicating that environmental regulation has an inverted U-shaped direct and spatial spillover effect on AGTFP. This is because the central region has been undertaking the industrial transfer from the eastern developed region for a long time, resulting in serious non-point source pollution in the central region, poor long-term living environment for residents, low AGTFP, and a small improvement in residents' well-being. However, with the continuous environmental regulation, agricultural producers' awareness of environmental protection has gradually increased, which promotes AGTFP. However, after the critical point of the intensity of environmental regulation, due to the lack of the central region technology innovation power, agricultural producers will increase pollution control inputs to meet regulatory requirements, reducing the profits of agricultural producers, and some agricultural producers will turn to non-agricultural sector employment, resulting in the brain drain phenomenon, inhibiting AGTFP. This is not conducive to the sustainable development of agriculture and the improvement of the welfare of the agricultural sector. In the west, environmental regulation has a U-shaped relationship with both local and neighboring AGTFP, which is consistent with the previous conclusions.

Non-major grain-producing areas include several developed provinces with high innovation levels and initial AGTFP at a high level. With the continuous improvement of environmental regulation intensity, the impact on AGTFP is first inhibited and then promoted. In major grain-producing areas, the relationship between environmental regulation and AGTFP presents an inverted U shape. The reason is that most of the provinces included in the major grain-producing areas are located in the central region, where technological innovation is insufficient and the initial AGTFP level is low. Only appropriate environmental regulation intensity can significantly promote AGTFP and the welfare level of the agricultural sector.

Table 8. Estimated results of the spatial Durbin model at the regional level.

Variable	(1) East	(2) Central	(3) West	(4) Non-Major Grain-Producing	(5) Major Grain-Producing
ENV^2	5.3519 (6.4278)	−322.7252 ** (147.7258)	0.2249 *** (0.0823)	0.2011 *** (0.0486)	−47.3275 *** (11.4552)
ENV	−6.0041 *** (2.2717)	3.1338 (7.3131)	−0.9198 *** (0.3208)	−0.8181 *** (0.2029)	9.7217 *** (2.6642)
INS	0.8444 (0.6927)	6.4014 *** (0.5888)	4.7482 *** (0.7856)	4.5043 *** (0.3770)	5.5000 *** (0.6405)
ADR	−0.0937 (0.2355)	−0.2814 (0.2219)	−0.7063 ** (0.2811)	−0.3774 ** (0.1762)	−0.4268 (0.2822)
MAC	0.4361 *** (0.1412)	−0.0287 (0.2336)	−0.9596 * (0.5577)	0.1857 (0.1470)	1.5270 *** (0.2406)
EDU	0.0626 ** (0.0281)	0.0100 (0.0349)	−0.0396 (0.0500)	0.0420 (0.0344)	−0.0817 *** (0.0309)
TRA	−0.3579 *** (0.1141)	−0.8726 (0.8042)	2.6037 *** (0.6494)	0.3935 *** (0.0707)	0.2113 (0.1756)
W * ENV^2	−62.3126 (50.2356)	−540.0131 ** (210.1607)	0.9888 ** (0.4920)	0.3747 *** (0.1273)	−101.6237 *** (39.1461)
W * ENV	9.7881 (9.7816)	49.1696 *** (13.2604)	−4.1944 ** (2.0816)	−1.6137 *** (0.5565)	−0.3927 (5.5395)
W * INS	3.8251 * (2.0356)	−1.5325 (1.2463)	16.9088 *** (4.5052)	4.1521 *** (0.9653)	0.2550 (2.0887)
W * ADR	0.7798 (0.5874)	0.2893 (0.3436)	−1.5453 (1.3668)	0.0467 (0.3135)	0.3746 (0.5260)
W * MAC	−0.3388 (0.2705)	−0.4302 (0.4896)	0.7369 (3.3603)	0.1525 (0.1596)	0.7880 (0.5397)
W * EDU	−0.1437 (0.1713)	−0.0355 (0.1045)	−0.9015 *** (0.3426)	−0.0043 (0.0520)	−0.1951 * (0.1180)
W * TRA	−1.7413 *** (0.3868)	−2.3149 (1.5657)	10.2701 *** (2.9718)	0.3723 ** (0.1655)	−2.2773 (1.5060)
Spatial ρ	−0.2242 * (0.1235)	−0.3995 *** (0.0860)	−1.2192 *** (0.2258)	0.1731 ** (0.0738)	−0.2900 *** (0.1064)
Within -R^2	0.2342	0.0359	0.2805	0.1583	0.4164
N	220	160	220	340	260

Note: * $p < 0.1$ ** $p < 0.05$, *** $p < 0.01$.

4.5. Robustness Tests

In order to verify the robustness of the above empirical results, that is, that the direct impact of environmental regulation on AGTFP presents a U-shaped feature and its spatial spillover effect, this paper adopts four methods to test the robustness. First, the primary and quadratic coefficients of environmental regulation are incorporated into the benchmark regression model for testing. Second, the setting form of the space matrix is changed [58]; that is, we build the space weight matrix by the reciprocal distance between different regions and incorporate it into the model for empirical testing. Third, considering the weak spatial correlation of AGTFP in 2017–2020, the robustness test is conducted by reducing the interval. Fourth, considering the existence of reverse causality will lead to endogenous problems in the model, that is, that the change of AGTFP will adversely affect the promulgation of environmental regulation, this paper lags the explanatory variables and all control variables by one period, trying to weaken reverse causality to some extent.

Table 9 shows the results of the robustness test. It can be seen that in regression 1, the primary term of environmental regulation significantly negatively affects AGTFP, which is similar to the results of Liang et al. (2012) [12]. The coefficient of the secondary term of environmental regulation is also significantly negative, indicating that environmental regulation has a significant nonlinear effect on AGTFP. In Regression (2) to Regression (5), except for the difference in coefficient size, the significance and sign of the core explanatory variables are basically consistent with the results of the benchmark regression model (Table 5), indicating that the conclusions of the paper are robust.

Table 9. Robustness test results.

Variable	Regression 1	Regression 2	Regression 3	Regression 4	Regression 5
Direct					
ENV^2		−0.0220 ** (0.0095)	0.1435 ** (0.0582)	0.2043 *** (0.0591)	0.2117 *** (0.0600)
ENV	−0.0973 ** (0.0386)		−0.5335 ** (0.2398)	−0.8472 *** (0.2455)	−0.8638 *** (0.2521)
INS	3.3404 *** (0.3104)	3.2198 *** (0.3130)	3.5291 *** (0.3094)	2.6426 *** (0.2994)	3.7969 *** (0.3021)
ADR	−0.4903 *** (0.1625)	−0.5348 *** (0.1637)	−0.6365 *** (0.1741)	−0.4236 *** (0.1552)	−0.3275 ** (0.1646)
MAC	0.4393 *** (0.1194)	0.4081 *** (0.1209)	0.4380 *** (0.1247)	0.5269 *** (0.1356)	0.4762 *** (0.1257)
EDU	−0.0018 (0.0288)	0.0016 (0.0291)	−0.0293 (0.0317)	0.0497 (0.0560)	−0.0141 (0.0371)
TRA	0.1293 * (0.0724)	0.1278 * (0.0731)	0.1202 (0.0777)	0.0208 (0.0782)	0.1157 (0.0782)
Indirect					
ENV^2		−0.1259 *** (0.0315)	0.6897 *** (0.1703)	1.1595 *** (0.1945)	1.2509 *** (0.1578)
ENV	−0.6071 *** (0.1247)		−3.3178 *** (0.7084)	−5.0761 *** (0.8290)	−5.5280 *** (0.6726)
INS	2.4637 * (1.3831)	2.7153 * (1.4037)	−2.4693 *** (0.8404)	1.7937 (1.4669)	1.4869 (1.1024)
ADR	−0.8963 * (0.5023)	−1.1095 ** (0.5185)	0.2402 (0.3756)	−0.2422 (0.4748)	−0.1907 (0.4214)
MAC	0.5025 * (0.2565)	0.5132 * (0.2646)	0.3897 * (0.2098)	0.6209 * (0.3463)	0.3645 (0.2313)
EDU	0.0385 (0.0663)	0.0500 (0.0682)	0.0238 (0.0496)	−0.0498 (0.1957)	0.0505 (0.0674)
TRA	−0.5288 * (0.3068)	−0.4557 (0.3166)	−0.8137 *** (0.2278)	−0.7951 *** (0.3074)	−0.5552 ** (0.2497)
Spatial	0.3246 *** (0.0654)	0.3454 *** (0.0646)	−0.2658 *** (0.0944)	0.2977 *** (0.0799)	0.1296 * (0.0745)
Within-R^2	0.4628	0.4540	0.4037	0.4282	0.3656

Note: ① Regression (1) and Regression (2) represent the spatial Durbin model under fixed effects that only include the primary term of environmental regulation or the quadratic term of environmental regulation, Regression (3) represents the spatial Durbin model under the fixed effect of the inverse geographic distance weight matrix, Regression (4) represents reduction interval (2001–2016) spatial Durbin model under fixed effects, and Regression (5) represents explanatory variable lag one-period spatial Durbin model under fixed effects; ② * $p < 0.1$ ** $p < 0.05$, *** $p < 0.01$.

5. Conclusions and Implications

5.1. Conclusions

Based on the panel data of 30 provinces in China from 2001 to 2020, this paper uses the spatial Durbin model to analyze the spatial spillover effect of environmental regulation on AGTFP and further examines the mediating effect of the urban-rural income gap. The study shows that first, AGTC promotes the continuous improvement of AGTFP, with an average annual growth rate of 3.27%, while the level of AGEC stays at a low level, and China's AGTFP has the potential to be further improved through AGEC. Second, the impact of environmental regulation on AGTFP is U-shaped; namely, environmental regulation's effect on AGTFP is a critical point. When productivity is the main goal in the short term, environmental regulation inhibits AGTFP, and it is not conducive to sustainable agricultural development and social well-being of human ascension; only in the long run, when sustainable development is the main objective, will environmental regulation promote AGTFP and the welfare of the agricultural sector. Third, there is regional heterogeneity in the impact of environmental regulation on AGTFP. In the eastern region, environmental regulation negatively affects AGTFP, while in the central region, the impact of environmental regulation on AGTFP shows an inverted U shape. In the western region, environmental regulation has a U-shaped direct effect and a spatial spillover effect on AGTFP. From the perspective of non-main grain-producing areas, environmental regulation firstly inhibits and then promotes AGTFP, while in major grain-producing areas, the impact of environmental regulation on AGTFP is an inverted U shape that promotes first and then inhibits. Fourth, environmental regulation through the urban-rural income gap affects AGTFP; that is, the urban-rural income gap acts as an intermediary variable. Short-term environmental regulation will widen the urban-rural income gap, suppress AGTFP, and hinder urban-rural integration and agricultural modernization; thus, it will reduce the overall welfare level of the whole society. Conversely, long-term environmental regulation will narrow the urban-rural income gap, promote AGTFP, achieve a win-win situation between urban-rural integration and sustainable agricultural development, and improve the well-being of human society.

5.2. Implications

The above conclusions provide important policy enlightenment for the Chinese government to improve environmental regulation and the agricultural development strategy characterized by green development.

First, it is necessary to attach importance to upgrading AGTC and promoting AGEC. Through the change of AGTFP and its effect decomposition, it can be seen that the main driving force of China's AGTFP is AGTC, while the contribution of AGEC is weak. Therefore, under the strategic background of promoting green sustainable development of agriculture and realizing agricultural modernization, it is necessary to continue to accelerate agricultural green technology innovation. At the same time, we must pay attention to promoting the optimal allocation of agricultural factor resources, improve AGEC, and then promote the further improvement of AGTFP, so as to effectively improve the welfare level of the agricultural sector.

Second, it is necessary to correctly understand the nonlinear influence of environmental regulation and pay attention to the rational use of environmental regulation. The conclusion of this study shows that the impact of environmental regulation on AGTFP is not just negative inhibition or positive promotion, but there is a reasonable range. Therefore, China's agricultural green development strategy cannot blindly pursue the increase in environmental regulation intensity but should comprehensively consider the endowment of agricultural resources in various regions and take measures according to local conditions. The government should be within a reasonable policy intensity, encourage agricultural producers to reduce the use of agricultural chemical production factors, adopt cleaner production factors and agricultural green production technology through environmental regulation to reduce agricultural pollution emissions and increase agricultural output value, thereby promoting AGTFP and increasing farmers' income and the level of human well-being.

Third, it is necessary to break the market segmentation and promote the regional coordination of provincial agriculture. This study shows that there is a significant spatial spillover effect of environmental regulation on AGTFP, indicating that in order to achieve the goal of green agricultural development, it is necessary to promote the coordination of inter-regional environmental regulation to improve the overall well-being of society through the coordinated development of different regions. However, the current scattered agricultural distribution pattern is not conducive to the realization of the spatial spillover effect of environmental regulation. Therefore, it is necessary to focus on large-scale agricultural production and strengthen the inter-regional agricultural linkages. On the one hand, the scale effect of agricultural production will reduce agricultural production costs, improve resource utilization efficiency, and help lower the threshold for agricultural producers to adopt green production technology, thus improving agricultural production efficiency and the well-being of the region. On the other hand, technological innovation in the region will drive the improvement of AGTFP in surrounding areas through the demonstration effect or positive external economic effects and finally realize the coordinated improvement of social welfare in different regions.

Fourth, it is necessary to correctly understand the nonlinear effect of environmental regulation on the urban-rural income gap and promote urban-rural integrated development. The mediation effect model test results show that environmental regulation has an inverted U-shaped impact on the urban-rural income gap, and the reduction of the urban-rural income gap is conducive to the improvement of AGTFP. Therefore, while paying attention to the ecological effect of environmental regulation, we should pay attention to the income distribution effect of environmental regulation. In view of the needs of the agricultural market, we should increase the quality training of the rural labor force, improve its competitiveness, and alleviate the income distribution gap between urban and rural areas. Only by correctly understanding the income distribution effect of environmental regulation and applying it into practice can the integration of urban and rural areas be accelerated and the sustainable development of agriculture be promoted so as to promote the high-quality development of the Chinese economy and the level of human social well-being.

5.3. Deficiencies and Prospects

Although the nexus between environmental regulation, rural-urban income gap, and AGTFP has been studied in depth, some limitations should be taken into account when developing similar topics. First of all, this study only calculates environmental regulation from the perspective of command and control. However, market incentives and voluntary environmental regulation may also have an impact on AGTFP. Secondly, the nonlinear spatial Durbin model is used in this study, and a robustness test with a spatial threshold model will enhance the credibility of this study. However, there is no perfect estimation method for the spatial threshold model at present. Therefore, using a spatial threshold model to analyze the effects of different types of environmental regulation on AGTFP seems to be a meaningful direction.

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