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The Role of Environmental Regulation and Agricultural Insurance Effect on Agricultural High Quality Development

-- Based on the analysis of two-way fixed effect from the perspective of behavior change

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Abstract: Under the background of "double carbon" goal and Rural Revitalization Strategy, agricultural high-quality development needs to coordinate the policy synergy effect of environmental regulation and agricultural insurance. Based on the perspective of behavior change, this paper uses the panel data of 31 provinces in China from 2014 to 2023 and the two-way fixed effect model to explore the impact mechanism of agricultural insurance on agricultural green total factor productivity through environmental regulation. The results show that: first, agricultural insurance significantly promotes the improvement of agricultural green total factor productivity, and environmental regulation plays an intermediary role in it; Second, the heterogeneity analysis shows that agricultural insurance plays a significant role in the eastern and western regions, but its effect on the central region is limited; Third, the conclusion is robust after eliminating abnormal samples, which verifies the key value of policy tools in optimizing factor input and promoting low-carbon transformation.

Keywords: Agricultural Insurance, Environmental Regulation, Agricultural Green Total Factor Productivity.

1. Introduction

In 2024, the No. 1 document of the Central Committee proposed that to promote Chinese style modernization, we must unswervingly consolidate the agricultural foundation and promote the comprehensive revitalization of the countryside. The report of the 20th National Congress of the Communist Party of China stressed that in order to achieve the goal of "accelerating the construction of a modern economic system and focusing on improving total factor productivity", and accelerating the construction of a modern agricultural economic system, we must solidly promote the revitalization of village industries, talents, culture, ecology and organizations, and improve agricultural total factor productivity [1][2]. Total factor productivity is an important indicator that reflects the internal production efficiency of the production system and measures the high-quality development of the economy [3]. China attaches great importance to how to improve the high-quality development of agriculture. In the strategic plan for Rural Revitalization (2018-2022) issued by the CPC Central Committee and the State Council, China stressed the need to "continuously improve agricultural innovation, competitiveness and total factor productivity" [4]. Agricultural total factor productivity essentially reflects the internal coordination degree of the agricultural production system and the input efficiency of various groups. Promoting its improvement is not only an important measure of China's food security, but also an important driving force to improve the quality of agricultural development and promote agricultural modernization. It is also the core symbol of new quality productivity in China's agricultural field [5][6].

Under the background of "large country and small farmers" in China, agricultural carbon emissions have been far higher than those in Europe and the United States, and agricultural pollution has become one of the main sources of ecological environment pollution. In the face of increasingly severe climate change, China actively undertakes the responsibility of reducing carbon emissions and promises to strive to achieve carbon peak by 2030 and carbon neutrality by 2060 (hereinafter referred to as "double carbon" goal). The No. 1 document of the central government still proposes to vigorously promote the green and sustainable development of agriculture. The destruction of the ecological environment in the process of agricultural production not only has a negative impact on the high-quality development of agriculture, but also has a serious obstacle to the realization of the "double carbon" goal. With the deepening of environmental governance, environmental regulation has gradually become a powerful tool for the government to coordinate economic growth and environmental protection [7]. Considering that environmental regulation mainly includes two kinds of regulation tools, namely, the command control type based on administrative regulations (hereinafter referred to as "command type environmental regulation") and the market incentive type based on economic means (hereinafter referred to as "market type environmental regulation"). As a key measure to deal with environmental pollution, environmental regulation not only plays a core role in pollution control, but also provides an important institutional guarantee for high-quality economic development. In addition, different environmental regulations may restrict each other, thus affecting the effect of environmental governance [8][9].

In the process of China's agricultural modernization, the risks of natural disasters, market fluctuations and other risks faced by agricultural production are increasing, and the traditional risk management methods have been difficult to meet the needs of modern agricultural development. As an effective risk transfer tool, agricultural insurance has become an important means to protect farmers' income and stabilize agricultural production [10]. The No. 1 document still anchored the "agricultural science and technology support", emphasizing the importance of improving the R&D and application level of agricultural machinery and equipment [11]. The State Administration of financial supervision, the Ministry of finance, the Ministry of agriculture and rural areas and the State Forestry and grass Administration jointly issued the notice on promoting the precision insurance and claims settlement of agricultural insurance, which requires "purifying the precision management of insurance", "improving the quality and efficiency of claims settlement services", and paying attention to the impact of the development of agricultural insurance on food safety [12]. Agricultural insurance has dual effects of security and policy in the high-quality development of agriculture. On the one hand, agricultural insurance promotes the diversification of farmers' financing channels and the purchase of advanced agricultural machinery and high-quality seeds, which has the effect of technological progress [13]; On the other hand, precise and effective post disaster compensation should be implemented to reduce farmers' production risks and encourage farmers to actively invest in advanced technological elements [14]. The use of green technology is conducive to reducing the intensity of non-point source pollution caused by the use of pesticides and fertilizers, achieving sustainable agricultural development and food security, and generating environmental effects [15]. Policy oriented agricultural insurance is an important starting point to promote the high-quality development of low-carbon agriculture, and has become a new productive force for the green and sustainable development of agriculture.

Existing literature on environmental regulation and agricultural green total factor productivity some scholars are based on the theory of the relationship between government and market, exploring the establishment of a dynamic adjustment mechanism of environmental regulation [16]; Or explore the similarities and differences in the development of agricultural green total factor productivity among provinces and regions in China from the perspectives of digital economy [17] and innovative measurement methods [18] [19]. The research on the efficiency of environmental regulation mainly focuses on the impact of environmental regulation intensity [20], environmental policies [21] and other factors on the carbon emission performance of industrial enterprises, or on the impact of different environmental regulation tools on the total carbon emissions [22], net carbon emissions [23], carbon emission intensity [24]. In the research on the relationship between agricultural insurance and agricultural green total factor productivity, most scholars analyze it from a variety of different perspectives, including agricultural technology progress [25], the construction of agricultural insurance development level index system [26], the analysis of regional heterogeneity [27], and the addition of different intermediate variables in the research. Few scholars use environmental regulation as an intermediary variable to explore the impact of agricultural insurance on agricultural green total factor productivity.

Based on the perspective of behavior change, this paper selects panel data and uses a two-way fixed model to analyze and test the impact of agricultural insurance and environmental regulation on improving total factor productivity and promoting high-quality agricultural development. It can relatively accurately grasp the impact of agricultural insurance and environmental regulation, and provide useful guidance in traditional agricultural insurance and improving agricultural productivity and high-quality development, in order to promote the high-quality development of agricultural and rural modernization, and help realize the goal of Rural Revitalization as soon as possible.

2. Theoretical Analysis and Research Hypothesis

2.1. Agricultural Insurance and Agricultural Green Total Factor Productivity

Agriculture is an industry greatly disturbed by natural factors and market factors [28], and its producers and operators are vulnerable to it. In order to disperse agricultural risks, stabilize farmers' income and ensure the healthy development of agriculture, the government uses agricultural insurance as a means to disperse agricultural risks. Most of the existing studies believe that agricultural insurance has a significant positive relationship with the improvement of agricultural green total factor productivity. On the one hand, we should improve the production enthusiasm of producers by dispersing and transferring risks to ensure the long-term and stable development of the industry [29]; On the other hand, agricultural insurance is risk compensatory. Due to the guarantee of funds, producers and operators are more willing to try new technologies to improve agricultural production efficiency, followed by an increase in external production investment in agricultural production, leading farmers to change the original production mode and agricultural industrial structure [30].

With the proposal of the "double carbon" goal, the carbon emissions in the production process of the agricultural sector began to receive widespread attention, and the path of agricultural insurance for carbon reduction effect is also very clear. Through guiding farmers to change the traditional mode of production, agricultural insurance improves the use efficiency of agricultural chemicals such as pesticides and fertilizers, and reduces the excessive use of these chemicals, thereby reducing the pollution to the ecological environment such as soil and water sources; By supporting farmers to carry out ecological friendly agricultural production activities such as afforestation and soil and water conservation, we can improve the agricultural ecological environment and enhance the stability and service function of the agricultural ecosystem. Agricultural insurance provides risk protection for farmers, reduces the losses faced by farmers due to market price fluctuations, and thus encourages farmers to plant green agricultural products with large market demand and high economic benefits. Agricultural insurance can further promote the green development of agriculture by supporting the industrialization of agriculture, promoting the extension and upgrading of the agricultural industry chain, and improving the added value of agriculture. In the process of claim settlement, farmers' agricultural production behavior is often supervised and guided, and farmers are required to comply with environmental protection laws and standards. Enhance farmers' awareness of environmental protection and urge them to pay more attention to environmental protection and resource conservation in agricultural production.

Agricultural insurance plays a significant role in improving agricultural green total factor productivity. It not only promotes the innovation and application of agricultural technology, improves the agricultural ecological environment, but also promotes the adjustment of agricultural industrial structure and improves farmers' awareness of environmental protection. These impacts jointly promote the sustainable development of agriculture and realize the win-win of economic and environmental benefits.

H1: Agricultural insurance helps to improve total factor productivity.

2.2. Agricultural Insurance, Environmental Regulation and Agricultural Green Total Factor Productivity

Agricultural green total factor productivity can generally be understood as the factor productivity of agricultural area calculated by comprehensively considering expected and unexpected output, in which the unexpected output mainly includes environmental factors such as carbon emissions in the process of agricultural production [31]. Strong environmental regulation can effectively control the proportion of unexpected output. Environmental regulation can affect the government, the public and farmers to make changes in the production and operation of agricultural products from the structure, technology, scale and other fields, thereby inhibiting carbon emissions, and playing a certain regulatory role between agricultural environmental protection and agricultural green total factor productivity [32]. Carbon emission efficiency refers to the economic benefits or added value generated by unit carbon emissions in a certain production process. Higher carbon emission efficiency means that more economic output can be obtained under the same carbon emission level, or less carbon emissions can be generated under the same economic output. One of the purposes of environmental regulation is to promote enterprises and industries to reduce carbon emissions and improve resource utilization efficiency and environmental performance. Therefore, carbon emission efficiency can reflect the implementation effect of environmental regulation to a certain extent, that is, environmental regulation promotes enterprises to adopt energy-saving and emission reduction technologies and optimize production processes through various policies and measures, so as to improve carbon emission efficiency.

When environmental regulation is strengthened, farmers' awareness of environmental protection will also be strengthened. In the production process, they will choose a more environmentally friendly production structure and factor input, which will reduce the intensity of carbon emissions. Therefore, reducing and fixing carbon in agriculture plays a vital role in improving agricultural green total factor productivity. Some scholars' research shows that agricultural insurance can effectively inhibit carbon emissions by changing farmers' production behavior, and also affect carbon sinks. Agricultural insurance ensures food security, and environmental regulations are implemented to reduce the use of pesticides, fertilizers and agricultural plastic films, reduce carbon emissions, gradually form a "grain oriented" planting structure, protect soil organic carbon, and better improve scale and efficiency.

H2: Agricultural insurance can improve agricultural green total factor productivity by strengthening environmental regulation.

3. Research Design

3.1. Data

This paper selects the agricultural stroll data of 31 provinces in China (except Hong Kong, Macao and Taiwan) from 2014 to 2023 to carry out the research. The variable data are mainly from the China Insurance Yearbook, China Rural Yearbook, China Environmental Statistics Yearbook, China Statistical Yearbook, the National Bureau of statistics, regulatory authorities and government departments.

3.2. Index Construction

3.2.1. Explained Variable

Agricultural green total factor productivity (ATFP). This paper refers to Li Gucheng (2014)'s practice of agricultural green productivity to build the measurement system of agricultural green total factor productivity. In addition, the index system was improved and calculated by DEA malquist index method based on the practices of Zhou Fafa and others. The index system is shown in Table 1.

Table 1. Agricultural green total factor productivity index system

Indicator type	Sub indicators	Specific indicators
Factor input	Labour	Employees in the primary industry (10000)
	Land	Sown area of crops (1000 hectares)
	Agricultural machinery	Total power of agricultural machinery (KWH)
	Irrigation water	Effective irrigation area (1000 HA)
	Chemical fertilizer	Net amount of chemical fertilizer (10000 tons)
Expected output	Total output value of agriculture, forestry, animal husbandry and fishery	Total output value of agriculture, forestry, animal husbandry and fishery (100 million yuan)
TFP decomposition	EFF	Efficiency index
	TE	Efficiency of technological progress
	PE	Change in pure technical efficiency
	SE	Change rate of scale efficiency

3.2.2. Explanatory Variables

Agricultural insurance scale (AIns). Because few data are concentrated on the integration of agricultural credit asset data of major banks, it is impossible to accurately extract the corresponding performance of the agricultural sector; The relevant issues of insurance premiums and insurance expenditure are relatively vague, so this paper selects the ratio of property insurance premium income to agricultural insurance premium expenditure in each province of the country as a measure of the performance of financial institutions in each province in terms of compensation ability for agricultural insurance.

3.2.3. Intermediary Variable

Environmental regulation (ACEI). Most scholars in the existing literature choose to use the logarithm of environmental protection expenditure in local finance as the variable, which ignores the part of environmental protection expenditure for other industries. In order to make this indicator more effective in the study and more accurately reflect the effect measurement of the government departments in the implementation of agricultural environmental regulation, this paper uses the efficiency of agricultural carbon emissions in each region to express the environmental regulation.

As a policy tool to promote green development, the purpose of environmental regulation is consistent with the goal of improving the efficiency of carbon emissions. Therefore, taking carbon emission efficiency as an alternative variable of environmental regulation can study the impact of environmental regulation on economic growth, industrial structure adjustment and other aspects from the perspective of green development and low-carbon economy, and provide the basis for formulating relevant policies.

Compared with the direct measurement of the intensity and strictness of environmental regulation, the data of carbon emission efficiency is relatively easier to obtain, and has clear statistical standards and calculation methods. Many countries and regions have officially released carbon emission data and economic output data, which have been collected and collated by professional statistical institutions and have high credibility.

The carbon emission efficiency index is mainly measured by using DEA Malmquist index model based on the practices of shixiaoyan, Wang Yinxiang [33] and others. The index system is shown in Table 2.

Table 2. Carbon emission efficiency index system

Index	Index sub item
Input index	Agricultural sown area (1000 hectares)
	Agriculture, forestry, animal husbandry and fishery employees (10000 people)
	Application amount of agricultural chemical fertilizer (10000 tons)
	Total power of agricultural machinery (KWH)
	Pesticide usage (10000 tons)
	Usage of agricultural plastic film (ton)
	Effective irrigation area (1000 HA)
Expected output	Total output value of agriculture, forestry, animal husbandry and fishery (100 million yuan)
Unexpected output	Agricultural carbon dioxide emissions (tons)

Among them, the carbon emission coefficient method is used to calculate the unexpected output of agricultural carbon dioxide emissions, mainly referring to the practice of Fang Fang, Zhao Jun [34] and others, that is, the carbon emissions of six types of carbon sources are multiplied by the corresponding carbon emission coefficient and then summed, and the formula is as follows:

$$TCEI = \sum_{i=1}^{6} CEI_i = \sum_{i=1}^{6} \alpha_i \bullet X_i$$

Where, ai represents the carbon emission coefficient of each type of carbon source, Xi represents the carbon emission, and TCEI represents the total carbon emission. Table 3 shows a more detailed description.

Table 3. Carbon source emission coefficient

Carbon source emissions	Emission coefficient	Unit	Reference source
Chemical fertilizer	0.8956	kg/kg	Oak Ridge National Laboratory
Pesticide	4.9341	kg/kg	Oak Ridge National Laboratory
Agricultural film	5.1800	kg/kg	Institute of agricultural resources and ecological environment, Nanjing Agricultural University
Agricultural diesel	0.5927	kg/kg	IPCC(2006)
Agricultural sown area	3.1260	kg/hm^2	College of biology and technology, China Agricultural University
Agricultural irrigation area	25.0000	kg/hm^2	Dubey(2009)

3.2.4. Control Variables

Based on the practices of Zhou Fafa, Lishanshan and others, five influencing factors, including agricultural structure, degree of opening to the outside world, disaster rate, utilization rate of agricultural irrigation water and the level of agricultural fiscal expenditure, were selected as control variables. Details are shown in Table 4.

Table 4. Control variables

	Variable	Symbol	Variable definition
Control variable	Agricultural structure	Structure	Proportion of grain sown area in crop sown area
	Degree of opening to the outside world	Open	Ratio of total import and export volume of each region to regional GDP
	Disaster rate	Dar	Ratio of damaged area of crops to sown area of crops
	Agricultural irrigation water utilization ratio of effective	Water	Ratio of effective irrigation area to crop planting area in each region
	Agricultural fiscal expenditure level ratio	Agov	Ratio of agricultural, forestry and water expenditure to local fiscal expenditure

4. Empirical Analysis

4.1. Measurement of Agricultural Green Total Factor Productivity

4.1.1. Definition of Malmquist Index

Suppose there are n decision-making units, and each decision-making unit obtains s outputs with m inputs in t period.

$x_j^t = (x_{1j}^t, x_{2j}^t, ..., x_{mj}^t)^T$ represents the input index value of the j-th decision-making unit in period T.

$y_j^t = (y_{1j}^t, y_{2j}^t, ..., y_{nj}^t)^T$ is the output index value of the j-th decision-making unit in period T, and both are positive numbers, $t = 1,2,...,T$.

Under the condition of constant return to scale, let the distance function of (x^t, y^t) be $D_C^t(x^t, y^t)$ in t period and $D_C^{t+1}(x^t, y^t)$ in T+1 period; The distance function of (x^{t+1}, y^{t+1}) in t period is $D_C^t(x^{t+1}, y^{t+1})$, and the distance function in T+1 period is $D_C^{t+1}(x^{t+1}, y^{t+1})$.

In the case of variable returns to scale, let the distance function of (x^t, y^t) be $D_V^t(x^t, y^t)$ in t period and $D_V^{t+1}(x^t, y^t)$ in T+1 period; The distance function of (x^{t+1}, y^{t+1}) in t period is $D_V^t(x^{t+1}, y^{t+1})$, and that in T+1 period is $D_V^{t+1}(x^{t+1}, y^{t+1})$.

Under the technical conditions of stage T, the change value of technical efficiency from stage T to stage T+1 is:

$$M^t = \frac{D_C^t(x^{t+1}, y^{t+1})}{D_C^t(x^t, y^t)}$$

Under the technical conditions of T+1 phase, the change value of technical efficiency from t phase to t+1 phase is:

$$M^t = \frac{D_C^{t+1}(x^{t+1}, y^{t+1})}{D_C^{t+1}(x^t, y^t)}$$

The change of productivity from period T to period t+1 can be obtained by calculating the aggregate average value of the above two Malmquist productivity indexes:

$$M(x^t, y^t, x^{t+1}, y^{t+1}) = (M^t \times M^{t+1})^{\frac{1}{2}} = [\frac{D_C^t(x^{t+1}, y^{t+1})}{D_C^t(x^t, y^t)} \times \frac{D_C^{t+1}(x^{t+1}, y^{t+1})}{D_C^{t+1}(x^t, y^t)}]^{\frac{1}{2}}$$

4.1.2. Decomposition Form of Malmquist Index

Fgnz model decomposes Malmquist index into comprehensive technical efficiency change index and technical progress index, and further decomposes the comprehensive index into pure technical efficiency change index and scale efficiency change index, which is the same as the evaluation result of DEA model. In 1997, ray and desli revised the fgnz model and put forward the RD model with Malmquist exponential decomposition. The decomposition form is as follows:

$$M_{RD}(x^t, y^t, x^{t+1}, y^{t+1}) = \frac{D_V^{t+1}(x^{t+1}, y^{t+1})}{D_V^t(x^t, y^t)} \times [\frac{D_V^t(x^t, y^t)}{D_V^{t+1}(x^t, y^t)} \times \frac{D_V^t(x^{t+1}, y^{t+1})}{D_V^{t+1}(x^{t+1}, y^{t+1})}]^{\frac{1}{2}}$$

$$\times [\frac{D_C^t(x^{t+1}, y^{t+1}) / D_V^t(x^{t+1}, y^{t+1})}{D_C^t(x^t, y^t) / D_V^t(x^t, y^t)} \times \frac{D_C^{t+1}(x^{t+1}, y^{t+1}) / D_V^{t+1}(x^{t+1}, y^{t+1})}{D_C^{t+1}(x^t, y^t) / D_V^{t+1}(x^t, y^t)}]^{\frac{1}{2}}$$

4.1.3. Economic Meaning of Malmquist Index

Malmquist index measures the dynamic change index of Malmquist index from t to t+1, expressed in M:

(1) When m>1, Malmquist index showed an upward trend from t to t+1, and the efficiency was improved;

(2) M=1, the Malmquist index remains unchanged from t to t+1, and the efficiency remains unchanged;

(3) M<1, Malmquist index decreased from t to t+1, and the efficiency also decreased.

The comprehensive technical efficiency change index is the catch-up trend of each observation object from t to t+1 relative to the production preface expressed by Tec, that is, the change degree of technical efficiency of the competent unit of the decision-making unit from t to t+1.

(1) Tec>1 indicates the improvement of technical efficiency, that is, the management mode and decision-making of the decision-making unit are correct;

(2) Tec<1 indicates the deterioration of technical efficiency, that is, the management mode and decision-making of the decision-making unit are incorrect;

The technical progress index (TC) represents the movement of the production frontier from bear t to t+1, reflecting the degree of changes in production technology.

For decision-making units with multiple inputs and outputs, the advantage of DEA model is that it does not need the specific measurement of input-output indicators. It can make projection analysis on decision-making units with invalid efficiency, so as to clarify the specific direction of efficiency improvement.

The efficiency evaluation of DEA model is based on the static efficiency of the data of each decision-making unit in the same period. However, the time series data of multiple indicators of 31 provinces from 2014 to 2023 will be analyzed in this paper. If the traditional DEA analysis method is still used, the progress of technical level will be ignored in the evaluation process, which is inconsistent with the fact, because the production technology of each year cannot be assumed to be the same. Therefore, this paper first uses DEA model to conduct static evaluation and analysis of the efficiency of six aspects of each province in China from 2014 to 2023, and then selects Malmquist index to conduct dynamic analysis of the panel data of each province in China from 2014 to 2023.

4.1.4. Agricultural Green Total Factor Productivity Evaluation and Malmquist Index Analysis

The relevant index data of agricultural green total factor productivity of 31 provinces in China from 2013 to 2023 are input into deap2.1 software, and the results are as follows:

Table 5. Relevant indicators of agricultural green total factor productivity from 2013 to 2023

Year	Technical Efficiency change index	Technical Progress index	Pure Technical Efficiency change index	Scale Efficiency change index	Malmquist index
2013-2014	0.980	1.092	0.991	0.990	1.070
2014-2015	0.997	1.055	0.983	1.015	1.051
2015-2016	0.951	1.098	0.982	0.968	1.044
2016-2017	1.010	1.066	1.000	1.010	1.077
2017-2018	1.005	1.087	1.006	0.998	1.092
2018-2019	0.987	1.117	1.001	0.986	1.102
2019-2020	1.012	1.090	1.002	1.011	1.103
2020-2021	0.957	1.159	0.998	0.959	1.109
2020-2022	0.946	1.16	0.987	0.958	1.097
2022-2023	0.977	1.064	1.002	0.974	1.040
Mean	0.982	1.098	0.995	0.987	1.078

The result in Table 5 is the comprehensive efficiency value of 31 provinces in China from 2014 to 2023 based on the constant return to scale, and the efficiency index value is 1, indicating that the agricultural green total factor productivity of the decision-making unit is relatively effective, which means that the agricultural green total factor productivity is low.

The analysis results show that the Malmquist index is in the range of more than 1 in the eleven years from 2013 to 2023, which shows that most regions in the country have achieved high-efficiency input-output of agricultural green total factor productivity, which also shows that the input costs of agricultural production factors in all provinces have been effectively utilized. On average, the total factor production efficiency increased by 2.4% annually. From the perspective of the technical efficiency change index, the average annual growth rate was 11.1% from 2007 to 2013. There were technological setbacks in 2018, 2020 and 2021, which meant that the efficiency gradually improved during this period. The differences in the above years are mainly due to the differences in the technical level of productivity and economic level faced by each time period.

According to table 6, it can be found that the total factor production efficiency value of all provinces in the country is greater than 1. Since the data of Tibet and Qinghai provinces and the data of municipalities directly under the central government are more abnormal than those of other provinces, these two provinces are temporarily removed from the analysis. The largest province in the rest is Guizhou Province, and the smallest is Shanxi Province. From the average point of view, the national technological progress index and Malmquist efficiency index are greater than 1, and the technical efficiency change index, pure technical efficiency change index and scale efficiency change index are less than 1. By observing the data in the table, it can be found that the reduction of pure technical efficiency of each decision-making unit is caused by the change of scale efficiency. At the same time, the technical progress index is greater than 1, indicating that the economic development efficiency of 31 provinces in China has increased year by year, and its development is generally driven by technical progress and scale development.

Table 6. Relevant indicators of regional green total factor productivity of agriculture from 2014 to 2023

Regional	Technical Efficiency change index	Technical Progress index	Pure Technical Efficiency change index	Scale Efficiency change index	Malmquist index
Beijing	0.944	1.101	1.000	0.944	1.039
Tianjin	0.965	1.119	1.005	0.960	1.079
Hebei	0.945	1.119	0.978	0.966	1.057
Shanxi	0.960	1.099	0.954	1.006	1.055
Inner Mongolia	1.000	1.066	1.000	0.999	1.066
Liaoning	0.959	1.106	0.969	0.989	1.060
Jilin	0.972	1.092	0.967	1.005	1.061
Heilongjiang	1.000	1.062	1.000	1.000	1.062
Shanghai	0.959	1.047	1.000	0.959	1.004
Jiangsu	0.966	1.105	1.000	0.966	1.067
Zhejiang	0.972	1.092	0.983	0.989	1.062
Anhui	0.962	1.108	0.982	0.980	1.066
Fujian	0.977	1.092	1.000	0.977	1.067
Jiangxi	0.984	1.092	0.967	1.017	1.074
Shandong	0.956	1.117	1.000	0.956	1.068
Henan	0.966	1.104	1.000	0.966	1.067
Hubei	0.978	1.105	0.997	0.980	1.080
Hunan	0.972	1.115	0.996	0.975	1.083
Guangdong	0.993	1.079	1.000	0.993	1.071
Guangxi	0.990	1.101	1.010	0.980	1.090
Hainan	1.000	1.100	1.000	1.000	1.100
Chongqing	0.990	1.104	0.998	0.992	1.092
Sichuan	0.981	1.097	1.000	0.981	1.076
Guizhou	1.018	1.114	1.011	1.007	1.134
Yunnan	0.998	1.107	1.024	0.975	1.105
Tibet Autonomous Region	1.042	1.093	1.000	1.042	1.139
Shaanxi	0.991	1.101	1.000	0.991	1.092
Gansu	1.004	1.111	1.002	1.002	1.116
Qinghai	1.014	1.130	1.000	1.014	1.146
Ningxia	0.985	1.093	1.005	0.980	1.077
Xinjiang Uygur Autonomous Region	1.000	1.080	1.000	1.000	1.080
Mean	0.982	1.098	0.995	0.987	1.078

4.2. Benchmark Model Construction

This paper uses a two-way fixed effect model to evaluate the impact of agricultural insurance on agricultural green total factor productivity. The benchmark model is set as follows:

$$ATFP_{it} = \alpha + \beta_1 AIns_{it} + \gamma X_{it} + \mu_i + \lambda_{it} + \varepsilon_{it} \quad (1)$$

$$ACEI_{it} = \alpha + \beta_2 AIns_{it} + \gamma X_{it} + \mu_{it} + \lambda_t + \varepsilon_{it} \quad (2)$$

$$ATFP_{it} = \alpha + \beta_3 AIns_{it} + \beta_4 ACEI_{it} + \gamma X_{it} + \mu_{it} + \lambda_{it} + \varepsilon_{it} \quad (3)$$

Where i represents 31 provinces, t represents the year, α is the intercept term, μ_i is the fixed effect of provinces, and ε_{it} is the random disturbance term. The explained variable

$ATFP_{it}$ is agricultural green total factor productivity, the explanatory variable $AIns_{it}$ is agricultural insurance, $ACEI_{it}$ is the intermediary variable, indicating the intensity of carbon emissions, and X_{it} is the control variable, including agricultural structure, disaster rate, agricultural irrigation water utilization rate, degree of opening to the outside world, and the level of agricultural financial expenditure.

4.3. Descriptive Statistics

The descriptive statistical results are shown in the table below.

Table 7. Descriptive statistics of variables

Variable type	Variable symbol	Variable name	Sample size	Mean	Standard deviation	Min	Max
Explained variable	ATFP	Agricultural total factor productivity	310	1.080	0.773	0.777	1.567
Core explanatory variable	AIns	Agricultural insurance scale	310	0.063	0.064	0.006	0.459
Intermediary variable	ACEI	Environmental regulation	310	0.797	0.270	0.235	1.000
Control variable	Structure	Agricultural structure	310	0.655	0.152	0.355	0.971
	Open	Open degree	310	1420.5	2028.9	0.078	12272.16
	Dar	Disaster rate	310	0.530	1.026	0	9.056
	Water	Water agricultural irrigation water rate	310	0.466	0.208	0.179	1.234
	Agov	Agricultural fiscal expenditure	310	1.385	0.506	0.511	3.006

4.4. Benchmark Regression

This part makes a quantitative analysis of the impact of agricultural insurance on agricultural green total factor productivity based on the model (1). The benchmark regression results show that the ATFP regression coefficient in column (1) is 0.295, which is significant at the 5% significance level; After adding control variables in column (2), the regression coefficient of ATFP became 0.225, which was also significant at the 5% significance level. No matter whether the control variable is included or not, the two show a significant positive correlation, which means that the development of agricultural insurance can significantly promote the improvement of agricultural green total factor productivity, and the empirical results of the control variable are basically consistent with the relevant literature, so hypothesis 1 is verified.

Table 8. Regression results

	(1)	(2)
	ATFP	ATFP
AIns	0.295**	0.225
	(2.115)	(1.547)
Structure		0.548**
		(2.164)
Open		0.000
		(0.993)
Dar		-0.000
		(-0.050)
Water		0.068
		(0.734)
Agov		-0.006
		(-0.243)
_cons	1.057***	0.654***
	(73.176)	(3.590)
Time	Yes	Yes
Individual	Yes	Yes
N	309	306
R2	0.132	0.145
F	4.089	2.951
***p<0.01", "**p<0.05", "*p<0.10		

4.5. Mediation Effect Test

This paper empirically tests the mediating role of environmental regulation, which is measured by carbon emission efficiency, in the process of agricultural insurance affecting agricultural green total factor productivity. The regression results are shown in Table 9. According to the regression analysis of models (1) - (3), the structure of column (1) is consistent with the benchmark regression results. The results of column (2) show that agricultural insurance is negatively correlated with the intensity of environmental regulation, that is, when agricultural insurance develops, the intensity of environmental regulation will be weakened, because environmental regulation has an inhibitory effect on carbon emission efficiency in the long run. Comparing the coefficient of agricultural insurance scale (AIns) in column (1) and column (3), it changed from 0.225 to 0.215, indicating that the impact of agricultural insurance on agricultural green total factor productivity is reduced, and environmental regulation plays a significant intermediary role. Hypothesis 2 is proved.

Table 9. Mediating effect test

	(1)	(2)	(3)
	ATFP	ACEI	ATFP
AIns	0.225	-0.781	0.215
	(1.547)	(-1.645)	(1.473)
Structure	0.548**	-0.200	0.546**
	(2.164)	(-0.241)	(2.152)
Open	0.000	-0.000	0.000
	(0.993)	(-0.788)	(0.960)
Dar	-0.000	-0.004	-0.000
	(-0.050)	(-0.194)	(-0.058)
Water	0.068	0.431	0.073
	(0.734)	(1.423)	(0.787)
Agov	-0.006	0.041	-0.006
	(-0.243)	(0.476)	(-0.223)
ACEI			-0.012
			(-0.640)
_cons	0.654***	0.748	0.663***
	(3.590)	(1.256)	(3.625)
Time	Yes	Yes	Yes
Individual	Yes	Yes	Yes
N	306	306	306
R2	0.145	0.237	0.147
F	2.951	5.376	2.786
***p<0.01", "**p<0.05", "*p<0.10			

4.6. Heterogeneity Analysis

Columns (1) - (3) of table 10 test the relationship between agricultural insurance and agricultural green total factor productivity from the west, East and central regions respectively. The regional division is mainly based on the relevant literature of Economic Research (2021) as a reference. The regression results show that the agricultural insurance in the central region has no significant effect on the improvement of agricultural green total factor productivity, while the eastern and western regions have a significant effect. The reasons for this difference may be: the agricultural insurance market in the eastern region is relatively mature, and agricultural producers can better use agricultural insurance to optimize the business scale, adjust the planting structure and promote low-carbon technology innovation, so as to promote the improvement of agricultural green total factor productivity. In contrast, the central region is a traditional agricultural region, and the past agricultural business model has made the local agricultural producers' response to agricultural insurance relatively slow, so the effect of agricultural insurance in improving the green total factor productivity of agriculture in the region is limited. In addition, due to the greater support of the central agricultural insurance fiscal subsidy policy in the western region, the role of agricultural insurance in improving its agricultural green total factor productivity is also more obvious.

Table 10. Heterogeneity test

	(1)	(2)	(3)
	ATFP	ATFP	ATFP
AIns	0.386	0.221	0.012
	(1.518)	(0.759)	(0.039)
Structure	1.139	0.327	0.198
	(1.642)	(0.980)	(0.359)
Open	-0.000	0.000	0.000
	(-0.709)	(1.609)	(1.188)
Dar	-0.067	0.014	0.006
	(-1.528)	(0.401)	(0.987)
Water	0.027	0.029	-0.718
	(0.090)	(0.280)	(-1.144)
Agov	0.018	0.079	-0.064
	(0.319)	(1.396)	(-1.431)
_cons	0.448	0.528**	1.258***
	(1.034)	(2.198)	(2.735)
Time	Yes	Yes	Yes
Individual	Yes	Yes	Yes
N	120	100	80
R2			
F			
***p<0.01", "**p<0.05", "*p<0.10			

4.7. Robustness Test

Table 11. Robustness test

	(1)	(2)
	ATFP	ATFP
AIns	0.271*	0.304*
	(1.799)	(1.886)
Structure		0.468
		(1.408)
Open		0.000
		(1.074)
Dar		0.000
		(0.059)
Water		0.056
		(0.385)
Agov		-0.018
		(-0.623)
_cons	1.062***	0.726***
	(66.911)	(3.309)
Time	Yes	Yes
Individual	Yes	Yes
N	270	270
R2	0.133	0.153
F	3.580	2.735
***p<0.01", "**p<0.05", "*p<0.10		

Given that the scale of the agricultural economy in the four municipalities directly under the central government accounts for a relatively small proportion in the overall economy, and more attention is paid to environmental protection (especially in Beijing), this may have an impact on the results of the regression analysis. Therefore, this paper re conducted the regression analysis after eliminating the samples of the four municipalities directly under the central government. The results show that the impact of agricultural insurance on agricultural green total factor productivity is significantly positive, which is consistent with the previous benchmark regression results, indicating that the result is robust.

5. Conclusion and Suggestions

5.1. Conclusion

This paper selects 31 provinces in China from 2014 to 2023 as the research object, takes the data of agricultural insurance and rural economy as the research index, and uses the intermediary effect model to quantitatively investigate the impact of the development of agricultural insurance on agricultural green total factor productivity. The results show that the development of agricultural insurance can improve agricultural green total factor productivity, and the conclusion is still robust after removing some samples. In the heterogeneity analysis, the provinces are divided into three parts according to the regional location. It is found that the development of agricultural insurance has a significant effect on the productivity improvement in the eastern and western regions, but not in the central region. The analysis of impact mechanism shows that agricultural insurance can improve agricultural green total factor productivity by strengthening environmental regulation.

5.2. Suggestions

5.2.1. Optimize the Input Structure of Agricultural Factors

In terms of labor input, in view of the small-scale and scattered operation of farmers in some regions of China, we should promote the transfer of labor-intensive industries from the east to the central and western regions, attract more agricultural population to work nearby, increase farmers' income, optimize the allocation of agricultural labor resources, and improve agricultural production efficiency. In terms of chemical input, we should build a perfect transformation mechanism of agricultural scientific and technological achievements, support the application of environment-friendly technologies from the laboratory to the farmland, and encourage agricultural enterprises to increase the R&D and promotion of fertilizer saving, disease resistance and other environment-friendly products. Guide farmers to choose a more environmentally friendly and clean operation mode in the production process.

5.2.2. Develop Green Agricultural Insurance Projects

We will continue to accelerate the popularization and application of agricultural green technologies. By increasing the form of financial subsidies, support agricultural insurance institutions to carry out a variety of new green agricultural insurance projects, such as agricultural green low-carbon technology insurance, agricultural chemicals reduction and efficiency insurance, agricultural pollution liability insurance, agricultural carbon sink price insurance, so as to promote the application and promotion of agricultural green technology, reduce the excessive dependence of agricultural production on resources and environment, and finally realize the sustainable growth of agricultural green total factor productivity. Improve farmers' awareness of environmental protection in production, promote the development of innovative green technology, and let farmers actively carry out green production.

5.2.3. Formulate Environmental Control Policies According to Local Conditions

There are significant differences in environmental regulation between the central and western regions. At present, China's laws and regulations in the field of agricultural carbon emissions are still weak. Therefore, governments at all levels need to constantly improve relevant laws and regulations in combination with the actual situation of the region, so as to build a comprehensive and systematic legal system of agricultural carbon emissions and control agricultural carbon emissions more effectively. In this process, the central government should clarify the agricultural carbon emission standards in the assessment of local governments, and set up clear reduction performance evaluation indicators. This can not only promote local governments to take the initiative to take emission reduction measures, but also ensure that the whole emission reduction process is systematic, scientific and sustainable.

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