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Dynamic Relationship between Agricultural Technology Progress, Agricultural Insurance and Farmers' Income

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Abstract: The implementation of the agricultural insurance policy and advancement of agricultural technology has great significance for the development of the agricultural economy of China, and it is an important source of national stability and modernization and development of the agriculture sector. Agricultural insurance policy uses the expansion of agricultural technology progress in the process of evaluation, investigation and claims settlement, and so on. Agricultural technology progress is effective in the reduction of some agricultural risks, it also affects farmers' agricultural insurance behaviors, and optimizes the operating environment of agricultural insurance. The objective of this research is to explore the relationship between agricultural technology progress, agricultural insurance and farmers' income. It also explains the mutual/cooperative relationship between agricultural technology progress and agricultural insurance. It provides the theoretical basis and data support to verify the promotion effect of agricultural insurance and agricultural technology progress on farmers' income. This gives the improvement path for alleviating the spatial imbalance of China's agricultural development. Keeping in view the aforementioned background and this research explores the effects of agricultural technological progress and agricultural insurance on the farmers' income level. The panel data used for this research were from 2004 to 2019 and were grouped into two parts: high-density agricultural insurance areas and low-density agricultural insurance areas. The relationship between agricultural technology progress, agricultural insurance and farmers' income was estimated using the Panel Vector Autoregressive (PVAR) model. The results revealed that: (i) both agricultural technology progress and agricultural insurance have a positive effect on the farmers' income level, but this effect varies across regions; (ii) impact of the agricultural insurance on farmers' income is greater than the impact of agricultural technology progress on farmers' income; and (iii) the role of agricultural insurance in promoting agricultural technology progress exists only in areas with high-density agricultural insurance. Therefore, when formulating policies, the policymakers should consider regional differences and characteristics, and adopt development models keeping in view regional variations in adaptability with different agricultural insurance densities, Moreover, they should improve agricultural security policies, optimize agricultural capital allocation, promote the transformation of the agricultural economy from extensional growth to connotative growth, and further improve the agricultural productive income of rural residents.

Keywords: agricultural technology progress; agricultural insurance; farmers' income; PVAR

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1. Background and Introduction

Agriculture is an important part of economic development, a basic industry supporting national economic construction and development, and the most important material production department in national production and life. The agricultural economy is very rich, including not only crops, livestock and forestry related to large-scale agriculture, but also non-agricultural industries. In many areas, agriculture is the backbone of the local economy [1,2]. China is a largely agricultural country, with a wide variety of crops and a vast planting area. It is also the basic industry that ensures national production and life. The natural frangibility of agriculture requires the protection of the agricultural insurance escort [2]. In 2004, China began to experiment with Policy-oriented Agricultural Insurance. During that year, agricultural premium income reached USD 47.48 million. In 2007, the central government began to implement agricultural premium subsidy policies, making agricultural insurance one of the important means for the government to support "the agriculture, rural areas, and farmers" policy, China's agricultural insurance has since entered a stage of rapid growth. In 2021, according to the report of the Ministry of Finance of the People's Republic of China, China's agricultural insurance premium income reached USD 14.96 billion, becoming the country with the largest agricultural insurance premium in the world [3]. At the same time, with the transfer of China's rural labor, the development of modern agriculture requires the strong promotion of technological progress. The contribution rate of agricultural technological progress to China's agricultural growth has reached more than 60%. Today in China's agricultural transformation and development, studying the regularity of the dynamic relationship between agricultural technological progress and farmers' income growth based on the perspective of agricultural insurance development has important theoretical value and practical significance for exploring China's agricultural modernization development.

Agricultural insurance is a very important risk management tool, but its price is high and expected returns are not high, effective demand is small, and farmers' voluntary participation rate is low [4]. Premium income cannot make up for the payment of compensation, which may easily lead to the failure of the agricultural insurance market [5]. From the perspective of the development history of agricultural insurance in various countries, there is a high correlation and long-term stable synergistic interaction between the demand for agricultural insurance and farmers' income. It is expected that income, the risk appetite of farmers and the range of change will affect the demand for agricultural insurance by farmers. Therefore, in the absence of premium subsidies, the demand for agricultural insurance is small [6,7]. China's agricultural foundation is weak, the natural risks are numerous, and the production costs are high, resulting in low and unstable farmers' incomes. Farmers do not have sufficient funds to secure agricultural insurance [8]. When the income level is low, farmers will give priority to meeting basic living needs. Only when the income exceeds a certain level, the demand for agricultural insurance will be generated. And the increase in the demand for agricultural insurance is faster than the increase in farmers' income, which means that the primary task of developing agricultural insurance is to increase farmers' income [9]. At the same time, policy-based agricultural insurance can avoid agricultural risks and increase agricultural output. It is one of the important factors to increase farmers' income and has the welfare significance of smooth consumption and anti-poverty [10,11]. Although the payment of insurance premiums directly reduces the maximum disposable income of farmers, insurance compensation also reduces the risk of farmers getting a lower income [12]. Research evidence has shown that breeding sows' insurance can promote farmers to expand the number and scale of breeding [13]. The United States suffered a serious drought in agriculture in 2012, but the income of insured farmers increased [14]; Yamauchi [15] also confirmed the role of agricultural insurance in stabilizing farmers' income by using the rice insurance investigated in Japan. Therefore, China should innovate the farmers' income collection policy, strengthen the incentive measures for the development of agricultural insurance, and develop the agricultural product futures market [16]. However, some scholars believe that the role of agricultural insurance in increasing the income level of farmers is not significant, and even has certain negative effects. Therefore, agricultural insurance premium subsidy is the reason that promotes the growth of farmers' income [17,18].

Agricultural technology is an important guarantee for farmers' agricultural production. Agricultural technology progress is conducive to improving agricultural production efficiency and is the key to improving productivity, sustainability and resilience in food production and agriculture to contribute to the agricultural economy. The improvement of farmers' income is the economic basis for promoting the extension of agricultural technology, and also the basic measure to increase the adoption rate of agricultural technology by farmers [19]. Cavallo E et al. [20] found that farmers' demand for agricultural machinery and equipment depends on their income, and the improvement of farmers' income is conducive to the development of agricultural technology level. The progress of agricultural technology promotes the marginal output of agricultural products and increases the total supply, which leads to a decrease in the market price of agricultural products and the phenomenon of the decrease or slow growth of farmers' income [21]. Therefore, on the one hand, the promotion of agricultural technology improves the unit labor productivity of products, which makes the income of farmers increase. On the other hand, with the popularization of agricultural technology, the improvement of the overall technical level of the agricultural sector increases the total supply of the agricultural market, which in turn reduces the income level of farmers. This is the famous "agricultural treadmill hypothesis" [22]. However, most agricultural production is trapped by the mechanism of factors and product markets, making it difficult to achieve the purpose of increasing income from technological innovation [23]. With the development of technology and the deepening of research, the views of academia on supporting agricultural technological progress and increasing farmers' income have gradually increased. Agricultural technological progress can increase the utilization rate of labor capital and increase the degree of integration between agriculture and other industries, thereby generating new industries and increasing farmers' income [24]. The progress of agricultural technology has a significant role in promoting agricultural income and non-agricultural income, and the income of farmers with technical training is higher than that of other farmers [25,26].

Regarding the research between agricultural insurance and agricultural technology, early research suggests that China lacks a sound agricultural risk protection system, and the solidification of production models is not conducive to the development of agricultural technological progress [27]. The large-scale and specialized construction of agricultural production has continuously increased the production risks, and ordinary farmers are unable to bear the risks brought about by the use of new technologies. The innovation and application of agricultural production technologies have been hindered [28]. Based on this, No.1 Document of the Central Committee pointed out that the country should vigorously promote agricultural modernization, strengthen material equipment and technical support, strengthen the construction of modern agricultural industrial technology systems, and strive to reach the world's advanced level in major agricultural theories and cutting-edge core technologies. Due to its special nature, policy-oriented agricultural insurance can enable farmers to enjoy insurance benefits at a low price, reduce the harm of agricultural risks, reduce the risk of farmers adopting new technologies, improve the enthusiasm of farmers in the development and application of agricultural technologies, and promote the progress of agricultural technologies [29]. Agricultural insurance improves the frequency of use of fertilizers and pesticides, increases investment and production investment opportunities, and is conducive to the improvement of agricultural production technology and agricultural productivity [30,31]. However, farmers who have participated in agricultural technology training are less willing to buy agricultural insurance than those who have not participated in technical training, because they are more confident in coping with risks [32].

China is in a period of transition to a dual structure. Increasing farmers' income and promoting rural urbanization are very important to protect farmers' lives and improve agricultural production efficiency. The policy and welfare effects of agricultural insurance make it an important tool for the government to prevent and control agricultural production risks. Pre-disaster prevention and post-disaster transfers constitute a mechanism for agricultural insurance to ensure agricultural production. Insurance before the disaster guarantees farmers' enthusiasm for production. However, in the case of large losses, the farmers may give up the risk of prevention and control, and the investment in agricultural technology and the increase in income of farmers are also restricted by high risks. In low-risk situations, farmers are more willing to produce and are more willing to cooperate with the implementation and update of agricultural technologies.

Most of the existing literature still focuses on the discussion of the local relationship between agricultural technology progress, agricultural insurance and farmers' income, and even there are some disputes about this local relationship, lacking a unified framework for systematic analysis. Secondly, due to the different impact mechanisms of different agricultural insurance densities on farmers' income, there is still a lack of discussion on the impact of different agricultural insurance densities on farmers' income. Therefore, based on the agricultural insurance density, this paper will construct two groups of panel data of high agricultural insurance density and low agricultural insurance density, and use the Panel Vector Autoregressive (PVAR) model system to systematically study the agricultural technology progress, agricultural insurance and farmers' income, with a view to deeply analyzing the interaction relationship between the three, providing the theoretical basis and data support for the promotion of agricultural insurance and agricultural technology progress on farmers' income, It provides an improvement path for alleviating the spatial imbalance of China's agricultural development and provides a factual basis for promoting the development of China's Rural Revitalization Strategy.

2. Materials and Methods

2.1. Theoretical Framework

In the theory of technological progress in macroeconomics, materialized technological progress considers that capital productivity in period t depends on the technological level at that moment, and has nothing to do with technological progress after that period. Based on the deduction of Sato [33] and Romer [34] on the progress of physicochemical technology, assuming that the agricultural production function is

$$Y(t) = W(t)^{\alpha} L(t)^{1-\alpha} \tag{1}$$

Among them, W(t) is the effective capital stock, $\dot{W}(t) = sA(s)Y(t) - \delta W(t)$ determines the dynamic change of W(t), A(t) indicates that the productivity of investment formed at time t depends on the technical level at that time and s represents the saving rate at time t, and δ represents momentary depreciation rate at time t.

Define $\overline{W}(t) = \frac{W(t)}{A(t)}$, the production function can be expressed as

$$Y(t) = [A(t)[\overline{W}(t)]]^{\alpha} L(t)^{1-\alpha} \tag{2}$$

The two ends of the above formula are the same except $A(t)^{\alpha/(1-\alpha)}L(t)$, simplified to

$$\frac{Y(t)}{A(t)^{\alpha/(1-\alpha)}L(t)} = \left[\frac{\overline{W}(t)}{A(t)^{\alpha/(1-\alpha)}L(t)}\right]^{\alpha} \tag{3}$$

Define $\varphi = \alpha/(1-\alpha)$, $\overline{\varpi}(t) = W(t)/A(t)^{\varphi}L(t)$, the production function can be expressed as

$$Y(t) = A(t)^{\varphi} L(t) \overline{\varpi}(t)^{\alpha} \tag{4}$$

Divide both sides of the equation by $A(t)^{\varphi}L(t)$ to get the per capita form of agricultural output under physical and chemical conditions

$$y(t) = \overline{W}(t)^{\alpha} \tag{5}$$

However, to overcome the weak nature of agricultural production, technological progress alone is not enough. It is also necessary to establish an agricultural risk diversification mechanism to play the insurance guarantee function. Based on the research of Shao et al. [35], the agricultural risk is introduced into the model and established a model including the model of agricultural insurance guarantee. Introducing agricultural insurance elements Ris:

$$\mathrm{Ris}(t) = 1 - \mathrm{prob}_t \times \mathrm{tfp}_t \quad (6)$$

Among them, prob_t is the probability of occurrence of agricultural risks in period t, and tfp_t is the degree of decline in total factor productivity when agricultural risks occur in period t. Then the agricultural production function when there is agricultural insurance guarantee is:

$$y(t) = \mathrm{Ris}(t)\overline{\omega}(t)^{\alpha} \quad (7)$$

Define $z(t) = \overline{\omega}(t)^{\alpha}$, then the agricultural production function is

$$y(t) = \mathrm{Ris}(t)z(t) \quad (8)$$

Let m(t) be farmers' income. According to the relationship between output and income in macroeconomic theory, a linear relationship between agricultural production and farmers' income can be established, and then farmers' income and agricultural technical level can be established according to the above derivation. 1. The linear relationship between agricultural insurance protection (where λ, μ and ν are coefficients):

$$\frac{\dot{m}(t)}{m(t)} = \lambda\frac{\dot{y}(t)}{y(t)} = \mu\frac{\dot{\mathrm{Ris}}(t)}{\mathrm{Ris}(t)} + \nu\frac{\dot{z}(t)}{z(t)} \quad (9)$$

Combined with the above analysis, short-term investment in agricultural technology development will reduce farmers' income, but agricultural labor-saving technological advances represented by agricultural mechanization can reduce the unit cost of agricultural production, promote the increase in agricultural productivity and increase in total agricultural output, and, thus, affect farmers Income level. Therefore, the improvement of agricultural technology level will directly promote the increase of farmers' agricultural income in the long run. From this, we can propose Hypothesis H1:

H1: *The improvement of agricultural technology level will reduce farmers 'income in the short term, but it can promote farmers' income in the long term.*

Agricultural insurance can participate in agricultural risk management, and effectively diversify, prevent and transfer various risks faced by agricultural production. Through the accumulation and dispersion of risks, it can reduce the disaster risks and losses faced by a certain area at a certain moment in space and time. Carry out assessments to reduce the sudden impact of natural disasters on rural poverty-stricken areas, thereby stabilizing farmers 'incomes, and ensuring and improving their products and lives. Therefore, we can propose hypothesis H2:

H2: *Agricultural insurance can help stabilize and protect farmers' income.*

As a tool to stabilize and improve farmers' income, agricultural insurance policy uses the expansion of agricultural technology progress in the process of evaluation, investigation and claim settlement, and so on. Agricultural technology progress is effective in the reduction of some agricultural risks, it also affects farmers' agricultural insurance behaviors, and optimizes the operating environment of agricultural insurance. It is obvious that there is a synergistic effect between agricultural technology and agricultural insurance on farmers' income. From this, hypothesis H3 can be put forward:

H3: *There is a synergistic effect between agricultural technology and agricultural insurance that helps to stabilize and protect farmers' income.*

2.2. Variable Selection

The selection of variables needs to consider the availability of data and can reflect the research content pertinently. Based on the current research and combined with the research perspective of this paper, this paper selects the following variable indicators.

2.2.1. Agricultural Technology Progress (TFP)

At present, most scholars mainly choose total factor productivity to measure the level of technological progress in the agricultural industry [36,37], and the methods used mainly use the non-parametric DEA-Malmquist index method to further decompose agricultural technology into technological progress and technical efficiency [38,39]. This paper imitates previous literature to use this method to measure and decompose agricultural technological progress. The input data include rural agriculture, forestry, animal husbandry and fishery employees, effective irrigated area, pure fertilizer application amount, rural electricity consumption, the number of large livestock at the end of the year, and total crops sown area. Output data are expressed by the total output value of agriculture, forestry, animal husbandry, and fishery. The agricultural total factor productivity index, which characterizes the progress of agricultural technology, is calculated using the DEA-Malmquist index method.

2.2.2. Agricultural Insurance (INS)

Agricultural insurance density is an important indicator for measuring the level of agricultural insurance development and represents the average level of agricultural insurance protection in a region. Ray P K. [40] measured the level of agricultural insurance development by per capita premium; Binswanger-Mkhize HP et al. [41] considered the welfare effect of agricultural insurance when studying the impact of agricultural insurance on agricultural output and used changes in agricultural premiums to indicate the level of agricultural insurance development. This paper mainly studies the relationship between the level of agricultural insurance development and other factors and selects the density of agricultural insurance to represent the level of agricultural insurance development. Similarly, when calculating the agricultural insurance density, the premium income of each region was adjusted to the actual output value in 2007 using the GDP deflator, and then divided by agriculture, forestry and animal husbandry. The number of employees in the fishery industry and the per capita premium represent the level of agricultural insurance development.

2.2.3. Farmers' Income (INC)

In this paper, the per capita net income of rural residents in each province is used to represent the income of rural residents. Its statistical significance is the part of the total income of rural residents directly used for production and non-productive construction investment, consumption, and savings, excluding expenses, taxes and other amounts [42].

2.3. Data Source

Based on the availability of data, this paper sets the research object as the inter-provincial panel data of 31 provinces, autonomous regions, and municipalities of China from 2004 to 2019. In the data on agricultural technology progress, the total sown area and effective irrigation area of crops are collected from the *China Statistical Yearbook* (http://www.stats.gov.cn/tjsj/ndsj/, accessed on 8 June 2022), the net amount of agricultural chemical fertilizer application, rural electricity consumption, number of large livestock at the end of the year, number of employees in agriculture, forestry, animal husbandry and fishery, and the total output value of agriculture, forestry, animal husbandry and fishery are collected from the *China Rural Statistical Yearbook* (https://data.cnki.net/yearbook/Single/N2021120010, accessed on 8 June 2022). In the data of agricultural insurance, the premium income of agricultural insurance is mainly collected from the *China Insurance Yearbook* (https://data.cnki.net/yearbook/Single/N2017030254, accessed on 8 June 2022), the number of employees in agriculture, forestry, animal husbandry, and fishery collected from the *China Rural Statistical Yearbook* (https://data.cnki.net/yearbook/Single/N2021120010, accessed on 8 June 2022). In the data on agricultural income, the per capita net income of rural residents was collected from the *China Statistical Yearbook* (http://www.stats.gov.cn/tjsj/ndsj/, accessed on 8 June 2022). Since price data are involved in the study, the impact of inflation will affect the analysis. Therefore, the actual income after deflation is based on the 2007 GDP deflator as the base period.

At the same time, in order to better study the regional differences in agricultural insurance, the 31 provinces were averaged for agricultural insurance density from 2004 to 2019 by region. If the regional average was greater than the national average, it was recorded as a high agricultural insurance density region, otherwise, It is a low agricultural insurance density area, and the specific grouping results are: Beijing, Fujian, Guangdong, Heilongjiang, Hubei, Jilin, Jiangsu, Liaoning, Inner Mongolia, Shandong, Shanghai, Tianjin, Xinjiang and Zhejiang are high agricultural insurance density areas (hereinafter referred to as High-density areas); Anhui, Gansu, Guangxi, Guizhou, Hebei, Henan, Hunan, Jiangxi, Ningxia, Qinghai, Shanxi, Shaanxi, Sichuan and Yunnan are low agricultural insurance density areas (hereinafter referred to as low-density areas).

Table 1 shows the descriptive statistical characteristics of agricultural technological progress, agricultural insurance, and farmers' income growth in various regions. It can be seen that the agricultural technology level and the average rural per capita net income of the high-density regional panel data H of the agricultural insurance density group are Obviously higher than the low-density area panel L, these statistical characteristics of the raw data to a certain extent prove the previous preliminary judgment of the economic and social characteristics of high-density and low-density areas.

Table 1. Statistical characteristics.

Variable Name	Mean	SD	Min	Max
Panel (National Region)				
Farmers' Income (USD)	1382.181	449.047	141.516	757.975
Agricultural insurance density (USD/per)	7.212	8.916	0.000	49.680
Agricultural Technology Progress	1.217	0.102	0.468	2.565
Panel H (High Density Area)				
Farmers' Income (USD)	1544.265	460.702	189.3	8184.332
Agricultural insurance density (USD/per)	10.321	11.457	0.000	49.724
Agricultural Technology Progress	1.118	1.139	0.468	1.923
Panel L (Low Density Area)				
Farmers' Income (USD)	1240.939	321.059	141.515	6417.911
Agricultural insurance density (USD/per)	2.178	2.527	0.000	11.712
Agricultural Technology Progress	1.213	0.088	0.921	1.620

2.4. Methods

2.4.1. Panel Vector Autoregressive (PVAR) Model

The vector autoregression (VAR) model established by Sims in 1980 [43] is characterized by taking all variables as endogenous variables to truly reflect the interaction between variables; Holtz Eakin extended it to panel data and put forward the panel vector autoregression (PVAR) model, which can perfectly combine the advantages of the cross-sectional data model and the time series model [44]. The data form is also expanded from the time series data to the panel data, which improves the accuracy and stability of the data results, takes into account the time effect and the fixed effect, and improves the accuracy and stability of the measurement results. Later, scholars further improved the panel vector autoregressive model and applied it to macro-dynamic research, making it a more powerful data processing model [45,46]. This paper makes a systematic analysis of the relationship between agricultural technology progress, agricultural insurance, and farmers' income. PVAR model analysis is generally based on the stationarity test, through the process of model estimation, impulse response, variance decomposition, and so on, to systematically analyze the interaction of various variables. Among them, the model estimation method mainly uses the generalized moment estimation (GMM) method to estimate the model parameters, and preliminarily discusses the interaction between the model variables. Impulse response function mainly measures the impact of random disturbance impact from an endogenous variable on the current value and future value of the variable itself and other endogenous variables. Variance decomposition is mainly used to measure the explanatory power of the impact of each endogenous variable on the changes of all endogenous variables. It can systematically analyze the relative importance of each impact on the endogenous variables, and further identify the interaction and impact between agricultural technology progress, agricultural insurance and farmers' income.

2.4.2. Empirical Model

Based on the previous literature to analyze the impact mechanism of agricultural insurance and other factors, most of them use regression models for analysis but ignore the endogenous problems of the variables in the model. This paper draws on the practices of love I et al. [47] and Li H et al. [48] and uses the panel data from 2004 to 2019 to divide the whole country into high-density and low-density areas of agricultural insurance and builds a PVAR model to analyze the relationship among the three. To study the mutual impact and dynamic relationship between agricultural technological progress, agricultural insurance and farmers' income, this paper constructs the following PVAR model with j lags:

$$Y_t = \beta_0 + \sum_{j=1}^{k} \beta_j X_{it-j} + \gamma_i + \alpha_i + \varepsilon_{it} \quad (10)$$

where i = 1, 2, ..., N, for each province; t = 1, 2, ..., T, for each year; Y_{it} = [TFP, INS, INC], $X_{it} = [Y_{it-1}, Y_{it-2}, \ldots, Y_{it-j}]$, TFP represents agricultural technology progress, INS represents agricultural insurance, and INC represents farmers' income. To eliminate the possible heteroscedasticity of the sequence, logarithmic processing is performed on all three, and the co-integration relationship between the original sequences will not change; β_0 represents the vector of coefficient terms; k represents the lag order; and β_j represents the lag j the parameter matrix of order; γ_i is the individual effect vector, representing the difference of cross-section individuals; α_t is the time effect vector, representing the influence of time change on individuals; ε_{it} is the random disturbance term.

The development of China's agricultural insurance has regional characteristics. The agricultural resources in regions with high agricultural insurance density have higher investment, the agricultural industry system has a higher degree of modernization, and more attention to the role of agricultural technology progress in agricultural economic development. Secondly, the areas with a higher density of agricultural insurance tend to have a higher scale and intensive industrial production, higher income of agricultural production and its proportion in total income. Finally, the higher agricultural insurance density means that the region attaches great importance to agriculture and the policy is relatively perfect. Because different areas with different agricultural insurance density have different social form characteristics, according to the degree of agricultural insurance density, respectively construct panel H with high agricultural insurance density and panel L with low agricultural insurance density [35,49], then the formula can be further specifically transformed into the following PVAR forms:

$$Y_{it}^{h} = \beta_0 + \sum_{j=1}^{k} X_{np}^{h} TFP_{it-j} + \sum_{j=1}^{k} \Lambda_{np}^{h} INS_{it-j} + \sum_{j=1}^{k} \Pi_{np}^{h} INC_{it-j} + \gamma_i + \alpha_i + \varepsilon_{it} \quad (11)$$

The following formula is the PVAR model expression for low agricultural density areas:

$$Y_{it}^{l} = \beta_0 + \sum_{j=1}^{k} X_{np}^{l} TFP_{it-j} + \sum_{j=1}^{k} \Lambda_{np}^{l} INS_{it-j} + \sum_{j=1}^{k} \Pi_{np}^{l} INC_{it-j} + \gamma_i + \alpha_i + \varepsilon_{it} \quad (12)$$

Among them, in Equation (11), the explained variable $Y_{it}^{h} = [h\_TFP, h\_INS, h\_INC]$; in Equation (12), the explained variable $Y_{it}^{l} = [l\_TFP, l\_INS, l\_INC]$; β_0, X, Λ and Π are all coefficient matrices to be evaluated, γ_i, α_i and ε_{it} are individual effect, time effect, and random error term respectively.

3. Results

3.1. Stationarity Test of Variables

The panel data contain the time trend, and the stability of the variables in the model will be affected so that the model analysis is liable to fall into "false regression". By detecting the stability, the PVAR model can effectively avoid the "false regression phenomenon" Table 2.

Table 2. Unit root test results.

Sequence Name	Test Method	National Area	High Density Area	Low Density Area
ln INC	LLC	−7.9121 *** (0.000)	−4.932 *** (0.000)	−6.562 *** (0.000)
	Fisher-ADF	25.678 *** (0.000)	16.355 *** (0.000)	18.724 *** (0.000)
	IPS	−9.515 *** (0.000)	−6.760 *** (0.000)	−7.509 *** (0.000)
ln INS	LLC	−16.357 *** (0.000)	−18.067 *** (0.000)	−10.056 *** (0.000)
	Fisher-ADF	16.847 *** (0.000)	12.670 *** (0.000)	10.988 *** (0.000)
	IPS	−4.945 *** (0.000)	−2.729 *** (0.004)	−4.589 *** (0.000)
ln TFP	LLC	−11.799 ***(0.000)	−8.692 *** (0.000)	−8.876 *** (0.000)
	Fisher-ADF	17.617 *** (0.000)	10.856 *** (0.000)	13.969 *** (0.000)
	IPS	−7.775 *** (0.000)	−5.151 *** (0.000)	−5.189 *** (0.000)

Note: The *p* value of the test is in parentheses, and *** is significant at the levels of 1%.

According to the test, ln INS, ln INC and ln TFP passed the LLC homogeneous unit root test and the IPS heterogeneous root test. The data of the whole country have also passed the Breitung test, so they can be considered as stationary series and can be estimated by the PVAR model.

3.2. Choice of Lag Order

In order to ensure the validity of the parameter estimation of the PVAR model, the optimal lag time of the model should be judged first according to the statistical criteria of AIC, BIC and HQIC. At the same time, to facilitate the comparison between regions, the same lag order should be selected as much as possible; and in order to prevent samples, the loss of degrees of freedom should not be too large [50]. Based on the principle of the above selection, although the AIC test in the country is recommended for the third-order, BIC and HQIC both show the first order, so the first-order lag order is finally selected. At the same time, the optimal order of high-density regions is shown as second-order, but considering that its first-order and second-order are taken as low order, the lag order selected of the whole country and the two regions are all 1 (Table 3).

Table 3. Delay test results.

Lagging Order Number	National Area			High Density Area			Low Density Area		
	AIC	BIC	HQIC	AIC	BIC	HQIC	AIC	BIC	HQIC
1	−3.253	−2.123 *	−2.756 *	−2.641	−1.591	−2.561	3.76 *	−2.635 *	−3.395 *
2	−3.461	−2.016	−2.880	−3.247 *	−1.905 *	−2.712 *	−3.363	−1.942	−2.787
3	−5.892 *	−4.168	−5.257	−6.189	−4.542	−5.563	−5.523	−3.860	−4.897

Note: * indicates the optimal lag time selected under the corresponding criterion.

3.3. Stationarity Test of Variables

In order to obtain the mutual influence of each variable, the relationship is studied by using the PVAR model. The forward mean difference method is used to remove the fixed effect, and the mean difference method is used to remove the time effect. Among them, h_lnINS, h_lnINC and h_lnTFP are sequences after Helmert processing, respectively. L1 represents the variable with one lag period, and the statistical system of each variable is shown in Table 4.

Table 4. GMM estimation results of PVAR model.

Lagging Order Number	National Area			High Density Area			Low Density Area		
	H_lnINC	H_lnINS	H_lnTFP	H_lnINC	H_lnINS	H_lnTFP	H_lnINC	H_lnINS	H_lnTFP
H_lnINC	0.610	0.756 ***	0.126 ***	0.323	0.738 ***	0.136 **	1.267 **	0.669 ***	−0.108 ***
L_1	(0.049)	(0.000)	(0.000)	(0.370)	(0.000)	(0.019)	(0.004)	(0.000)	(0.007)
H_lnINS	0.192 ***	0.693 ***	0.013 **	0.021 ***	0.726 ***	0.1349	0.2519 ***	0.592 ***	0.009
L_1	(0.000)	(0.000)	(0.024)	(0.000)	(0.000)	(0.138)	(0.000)	(0.000)	(0.150)
H_lnTFP	0.042	2.481 ***	0.168 ***	0.028	1.639 **	0.147 **	0.034	3.918 ***	0.206 *
L_1	(0.140)	(0.001)	(0.001)	(0.277)	(0.031)	(0.018)	(0.036)	(0.000)	(0.007)

Note: The *p* value of the test is in parentheses, and ***, ** and * are significant at the levels of 1, 5 and 10% respectively.

As shown in Table 4, it can be seen from the national data that the impact of lagging farmers' income on their level is 0.6201, which is significant at the level of 1%. Similarly, China's agricultural insurance and agricultural technology progress lag the dynamic explanations are stronger than their own. At the same time, the impact of farmers' income and the inertia of agricultural insurance is obviously higher than the inertial development of agricultural technological progress.

From the perspective of different regions, the impact of agricultural insurance lagging behind one period on itself is not the same. At the same time, the impact of agricultural insurance lagging behind one period on agricultural technology progress in both regions is not significant, but the impact of agricultural technology progress on agricultural income and insurance is not significant in high-density regions, while in low-density regions, the impact of agricultural technology progress lagging behind one period on agricultural income and agriculture Industrial insurance is significant at 5 and 1%, respectively. It can be seen that in different regions, the influence of the three is also different. The GMM parameter estimation of PVAR can only reflect the dynamic simulation process between variables, not the causal logic relationship between economic variables, dynamic communication process, etc., so we need to use Granger test and impulse impact methods to deepen the research.

3.4. Granger Test Analysis

The Wald coefficient constraint test was used to further analyze the short-term dynamic effects between the agricultural technology progress, agricultural insurance, and farmers' income, and to investigate the Granger causes among the variables. As shown in the test results in Table 5: (i) In the whole and sub-region, the joint significance has passed the 5% significance test, which has verified the rationality of the model construction to a certain extent and explained that the joint effect of each variable has a significant predictive effect on the explained variables. (ii) There is a significant Granger causality effect between farmers' income and agricultural insurance, which indicates that the interaction mechanism between the two is obvious in the short term. The improvement of farmers' income level is conducive to the development of agricultural insurance, while agricultural insurance prevents agricultural risks, maintains the safety of agricultural production, and ensures the increase of farmers' income. This result is consistent with theoretical hypothesis H2. (iii) There is a significant Granger causality effect between farmers' insurance and agricultural technology progress, which indicates that the short-term mutual dynamic driving effect between farmers' insurance and agricultural technology progress is obvious. Agricultural insurance ensures the safety of agricultural production, provides a basis for farmers to optimize resource allocation, and thus improves agricultural technology progress. (iv) Farmers' income is the one-way Granger cause of agricultural technology progress, which indicates that the increase of farmers' income in the short term has a significant dynamic driving effect on promoting the development of agricultural technology progress. The investment in agricultural technology needs the support of funds. The increase in farmers' income can enable farmers to learn advanced agricultural technology, purchase agricultural production machinery, etc., thus bringing about the improvement of agricultural technology progress.

Table 5. Granger causality test.

Project	Causal Relationship	*p*-Value		
		National Area	High Density Area	Low Density Area
H_INC	H_INS	0.000	0.000	0.000
	H_TFP	0.141	0.276	0.348
	ALL	0.000	0.000	0.000
H_INS	H_INC	0.052	0.369	0.004
	H_TFP	0.001	0.030	0.000
	ALL	0.003	0.073	0.000
H_TFP	H_INS	0.026	0.138	0.151
	H_INC	0.000	0.002	0.007
	ALL	0.000	0.003	0.001

4. Impulse Response Function Analysis and Variance Decomposition

4.1. Impulse Response Function Analysis

After 500 simulations of Monte Carlo, an impulse response graph with a lag of 10 periods was obtained, which better shows the effect between the two variables when the other variables are unchanged. It reflects the current and multiple periods of endogenous variables after the random error term is impacted by a standard deviation (Figures 1 and 2).

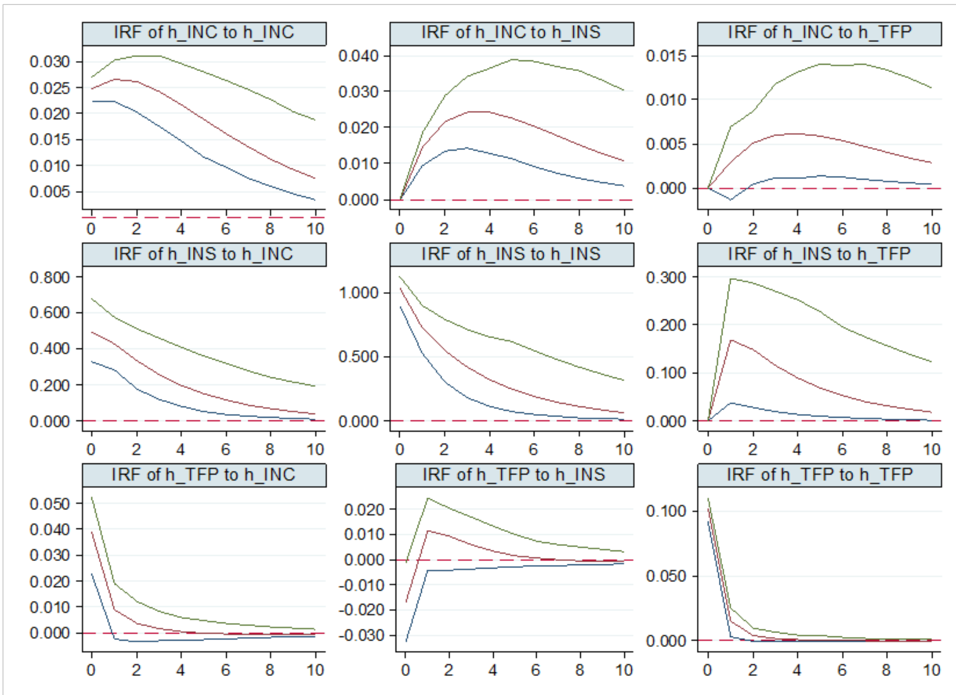

Figure 1. Impulse response diagram in high density areas.

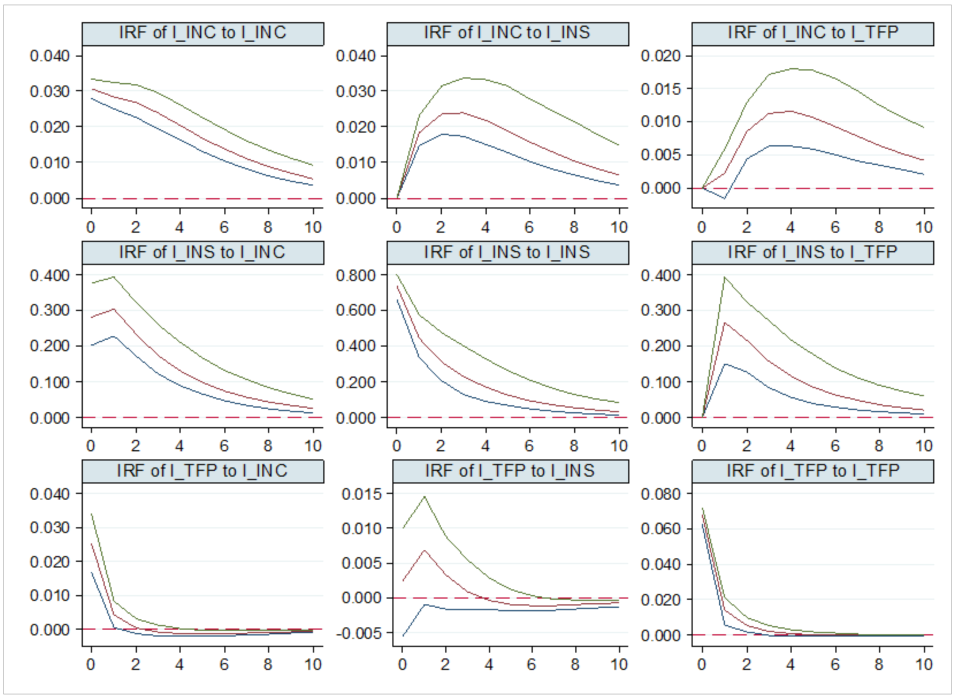

Figure 2. Impulse response diagram in low density areas.

Through comparative analysis, we can see that: (i) generally speaking, the economic variables in the two types of regions have a positive impact on them. After being impacted by a standard deviation, they are all greater than zero, and the current period is the maximum. As the number increases, the response slowly weakens and gradually approaches zero. Among them, the impact of agricultural technological progress on itself has greatly weakened since the beginning of the second phase. In low-density areas, the response of farmers' income to themselves has begun to slow down in the second phase. It shows that all three economic variables have a positive effect that depends on their inertia, and they show a weakening trend. (ii) In the impact of agricultural insurance on agricultural technological progress, the two types of regions are different. High-density areas reach their maximum in the first period and gradually decrease, indicating that agricultural insurance has a continuously positive impact on agricultural technological progress. The reason is that the development of agricultural insurance provides a good foundation for the improvement of agricultural technology. The policy oriented agricultural insurance enables the government to strengthen the investment in agriculture, increase the agricultural income of farmers, and provide guarantee for farmers' production. Low-density areas show different development paths. After being impacted by a standard deviation agricultural insurance, agricultural technology progress has a positive impact in the current period, and gradually decreases with the increase of the number of impact periods, after the fourth period. Entering a negative value indicates that agricultural insurance hurts agricultural technological progress, and it is generally a trend of decreasing first and then maintaining stability. This is because agriculture is fragile, and excessive reliance on agricultural insurance can lead to instability in agricultural economic development. (iii) There are also obvious regional differences in the impact of agricultural technological progress on farmers' income. High-density areas are the minimum in the first period and gradually increase afterward to stabilize and maintain an overall upward trend. The low-density area responds quickly, reaches its maximum in the third period, and then shows a downward trend. Its impact has a lag effect. However, the two regions have always maintained a positive relationship. It can be seen that agricultural technological progress has a positive impact on farmers 'income, indicating that the improvement of agricultural technological progress is conducive to the improvement of farmers' income. This result lends support to theoretical hypothesis H1. (iv) In the two regions, agricultural technology advancement and farmers' income impact on agricultural insurance have similar pulse effect diagrams. After being impacted, the current response value of agricultural insurance is positive, and the maximum value gradually decreases in the first period. It shows that the two have a continuously positive impact on agricultural insurance. The improvement of agricultural technological progress can promote the enthusiasm of farmers for production, increase the degree of emphasis on agriculture, and, thus, increase the emphasis on agricultural insurance. The increase in farmers' income levels provides an economic basis for insuring agricultural insurance.

4.2. Variance Decomposition

Variance decomposition can measure the impact of different shocks on the residuals. The variance of the prediction error of each endogenous variable is decomposed into the associated components of each variable, to measure the contribution of each shock to the fluctuation of the endogenous variable (Table 6).

Table 6. Results of variance decomposition.

Being Impacted Variable	Number of Periods	Shock Variables in National Area			Shock Variables in High Density Area			Shock Variables in Low Density Area		
		Ln INC	Ln INS	Ln TFP	Ln INC	Ln INS	Ln TFP	Ln INC	Ln INS	Ln TFP
Ln INC	1	0.8805	0.1215	0.0000	0.8881	0.1139	0.0000	0.8867	0.1133	0.0000
Ln INC	5	0.4621	0.5058	0.0331	0.4727	0.5080	0.0212	0.4866	0.4605	0.0539
Ln INC	10	0.3653	0.5888	0.0475	0.3615	0.6118	0.0287	0.4127	0.5119	0.0779
Ln INS	1	0.0000	1.0000	0.0000	0.0000	1.0000	0.0000	0.0000	1.0000	0.0000
Ln INS	5	0.0075	0.9364	0.0559	0.0031	0.9721	0.0268	0.0240	0.8572	0.1209
Ln INS	10	0.0082	0.9342	0.0596	0.0033	0.9691	0.0288	0.0269	0.8479	0.1255
Ln TFP	1	0.0584	0.0085	0.9352	0.0721	0.0003	0.9296	0.0502	0.0326	0.9191
Ln TFP	5	0.0567	0.0358	0.9095	0.0692	0.0353	0.8955	0.0488	0.0497	0.9033
Ln TFP	10	0.0573	0.0359	0.9087	0.0696	0.0358	0.8965	0.0495	0.0515	0.9019

From a nationwide perspective, in the error decomposition of agricultural insurance and agricultural technology progress, according to the results of the 10th period, its interpretation strength has reached 93.42 and 90.87%, respectively, which shows that the two mainly rely on their inertial development. In the decomposition of the error term of farmers' income, the interpretation of farmers' income by agricultural insurance has exceeded the influence of farmers' income on itself, because from 1st to 10th, the interpretation of farmers' income has changed from 88.05 to 36.53%, and the explanation of agricultural insurance has changed from 12.15 to 58.88%, and agricultural technology progress has only contributed 4.75% of the explanatory power. Therefore, the impact of agricultural insurance on farmers' income is greater than the impact of agricultural technology progress on farmers' income. The result lends support to theoretical hypothesis H3 that the synergy between agricultural technology and agricultural insurance contributes to the increase in farmers' income.

In terms of different regions, the dynamic relationship between agricultural technological progress, agricultural insurance and farmers' income is more complicated. First of all, among the three interpretation capabilities, the high-density area agricultural insurance has the smallest change in its interpretation strength, and the low-density area agricultural technology progress has the smallest change in its interpretation strength. Secondly, the ability of farmers' income to explain agricultural insurance in high-density areas increased from 11.39 to 61.18%, while in low-density areas rose from 11.33 to 51.19%, indicating that the impact of farmers' insurance on high-density areas on farmers' income is greater than that of low-density areas. At the same time, the explanation of agricultural technology progress in low-density areas for farmers 'income has changed from 0% in the first period to 7.79% in the tenth period, and the explanation of agricultural technology progress in high-density areas for farmers' income has been changed from 0% in the first period the change is 2.87% of the tenth period, so the agricultural technology progress in low-density areas has a greater impact on farmers' income than in high-density areas. Finally, for the error decomposition of agricultural insurance, the explanation of agricultural technology progress to agricultural insurance in low-density areas changes by 12.55%, which is far greater than that of agricultural technology progress to agricultural insurance in high-density areas by 2.88%, indicating that in areas with low agricultural insurance density, the impact of agricultural technology progress on agricultural insurance is greater than that in high-density areas.

5. Discussion

Most of the previous studies focused on the relationship between agricultural technology progress, agricultural insurance development and farmers' income. Few studies put the three into the same system. In this study, the PVAR model was constructed to study the interaction of the three.

Farmers need to pay a certain premium to participate in agricultural insurance, which will reduce farmers' income to a certain extent. After the risk occurs, although there is compensation from the insurance company, the income cannot reach the previous level, and the income will decrease. On the other hand, when disasters occur, insurance companies will compensate farmers, and farmers' income loss will be subsidized, which can stabilize farmers' income. This mechanism was also verified in the short-term effect test of this study. At the same time, due to the existence of a moral hazard, farmers understand that their losses will be compensated, their safety awareness will be weakened, and they ignore risk prevention and reduce the input and management of agricultural production. Therefore, long-term effect detection is required. The results of the long-term effect also show that the development of agricultural insurance has a long-term impact on the income of farmers in areas with high agricultural insurance density. It shows that in the long run, agricultural insurance contributes to the increase of agricultural income, and the increase is greater than the loss of premium payment and moral hazard.

After farmers participate in agricultural insurance, because production safety is guaranteed, farmers increase the input and use of various mechanical equipment, improve production efficiency and increase farmers' income. It can be seen that agricultural insurance can promote the progress of agricultural technology, improve the efficiency of agricultural production, promote the process of agricultural science and technology and modernization, and stabilize the development of agricultural production. The improvement of production efficiency and the progress of agricultural technology will also promote the production of agricultural products and increase the agricultural income of farmers. On the other hand, the increase of agricultural products may lead to the depreciation of agricultural products, thus reducing the income of farmers. However, from the long-term effect, agricultural insurance and agricultural technology progress will promote farmers' income. It can be seen that the market adjustment of agricultural products and the overall regulation and control of the state have ensured the positive role of agricultural insurance and agricultural technology progress.

6. Conclusions

There are great differences in agricultural technology progress, agricultural insurance and farmers' income in various regions of China. Based on the perspective of differences in agricultural insurance density, this paper classifies the panel data of 31 provinces in China from 2004 to 2019 into "high-density areas of agricultural insurance" and "low-density areas of agricultural insurance". It uses GMM Estimation of the PVAR model, panel Granger causality test, impulse response function, and variance decomposition econometric analysis to systematically study the dynamic impact relationship between agricultural technology progress, agricultural insurance and farmers' income, The following conclusions are obtained:

The grouping based on the high and low agricultural insurance density shows that Beijing, Fujian, Guangdong, Heilongjiang, Hubei, and other regions with high agricultural insurance density have high agricultural production mechanization and farmers' income; Anhui, Gansu, Guangxi, Guizhou, Hebei, and other low agricultural insurance density regions have low agricultural mechanization and farmers' income. High agricultural insurance density regions are higher than national regions in terms of farmers' income and agricultural technology progress. In different regions of agricultural modernization development, there are significant differences in the long-term dynamic relationship between agricultural technology progress, agricultural insurance and farmers' income, and the short-term dynamic effects are not obvious.

The short-term dynamic effect analysis of the panel Granger causality test found that there were mutual Granger reasons between agricultural income and agricultural insurance in various regions, indicating that there was a short-term dynamic driving effect between agricultural income and agricultural insurance; Agricultural income in each region is the one-way Granger cause of agricultural technology progress, and agricultural insurance and agricultural technology progress are Granger causes. This shows that in the short term, agricultural income and agricultural insurance have a significant dynamic driving effect on agricultural technology progress, and the increase of farmers' income, in turn, promotes the further development of agricultural insurance.

Impulse response and variance decomposition show that agricultural technology progress in the two regions has a significant long-term positive effect on Farmers' income, and, in turn, the increase of farmers' income is also conducive to the improvement of agricultural machinery technology level. The long-term positive effect of agricultural technology progress on agricultural insurance is significant in high agricultural insurance density areas, and agricultural technology progress has a high contribution to agricultural insurance. At the same time, in the low agricultural insurance density region, agricultural technology progress has a significant long-term expansion effect on the growth of farmers' income. Variance decomposition further confirms this conclusion. The long-term positive impact of agricultural insurance on farmers' income is not obvious in low agricultural insurance density areas.

Based on the above conclusions, this article obtains the following policy recommendations: when formulating relevant policies for agricultural insurance, we must first pay attention to the actual situation of farmers, stabilize agricultural production, and give full play to the role of agricultural benefits policies. Secondly, based on the long-term impact of agricultural insurance on farmers 'income in high-density agricultural insurance areas, when formulating agricultural insurance policies, we should understand the agricultural production conditions and characteristics in high-density areas according to local conditions. We cannot simply use agricultural subsidies to increase farmers' insurance enthusiasm. Finally, for areas with low agricultural insurance density, while increasing the emphasis on agricultural insurance, focus on improving the quality of agricultural mechanization, optimizing the allocation of resources for agricultural labor production, promoting the connotative growth of the agricultural economy, improving the level of farmers 'production and further increasing farmers' income.

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