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The Impact of Agricultural Insurance on Total Factor Productivity in Agriculture

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Abstract: ***Improving total factor productivity (TFP) in agriculture is essential for advancing agricultural modernization and ensuring food security. This study utilizes panel data from 30 Chinese provinces spanning 2011 to 2021 and employs a two-way fixed effects model to investigate the impact of agricultural insurance depth on agricultural TFP. A mediation model is further introduced to examine the intermediary role of agricultural mechanization within this relationship. The empirical results indicate that agricultural insurance significantly enhances TFP, with agricultural mechanization serving as a partial mediator. Moreover, regional heterogeneity is evident: the impact of agricultural insurance is more pronounced in the central and western regions, while the eastern region also shows a positive but comparatively moderate effect. This study underscores the mechanism linking insurance, mechanization, and TFP, offering empirical support for regionally differentiated agricultural insurance policies. The findings highlight the importance of refining insurance product design, promoting mechanization, and integrating insurance with agricultural risk management to enhance production efficiency.***

Keywords: Agricultural insurance; Total factor productivity; Agricultural mechanization; Regional heterogeneity.

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1. Introduction and Literature Review

Agriculture has long served as the cornerstone of China's national economy. Ensuring the stability of agriculture is essential to maintaining overall social and national stability. Since the 20th National Congress of the Communist Party of China, the central leadership has prioritized the modernization of agriculture and rural development. President Xi Jinping has emphasized the need to "focus on the development of modern large-scale agriculture and accelerate the modernization of agriculture and rural areas." In the context of the new era, developing modernized, large-scale agriculture is not only a key driver for the comprehensive revitalization of rural areas but also a strategic choice for safeguarding food security and establishing China as an agricultural powerhouse.

Amid growing global climate uncertainty and increasing pressure on agricultural resources, enhancing agricultural productivity and strengthening risk management have become critical priorities for advancing high-quality agricultural modernization. Agricultural insurance, as a key component of China's agricultural support and protection system, serves as a stabilizing force in ensuring national food security and sustainable agricultural development. In recent years, the Chinese government has underscored the importance of improving agricultural insurance. Notably, President Xi Jinping has called for expanding pilot programs for full-cost and income insurance and enhancing mechanisms to secure the income of grain producers. Consequently, academic interest in agricultural insurance has grown. However, existing studies have primarily focused on its roles in risk transfer and compensation, while research on how agricultural insurance influences production efficiency—particularly through incentivizing farmer behavior and upgrading production inputs such as total factor productivity (TFP)—remains limited and underdeveloped.

In recent years, the expansion of agricultural insurance coverage has increasingly revealed its incentive effect on agricultural TFP. Several empirical studies have identified a positive association between agricultural insurance and productivity outcomes. For example, Chen et al. [1] found that insurance payouts positively influence agricultural TFP. Similarly, Shen et al. [2] argued that agricultural insurance stabilizes production, boosts farmers' income, and provides income security through its risk-transfer function. Skees and Barnett [3] emphasized that agricultural insurance reduces the disruptive impact of natural disasters on farmers' production plans, thereby encouraging long-term investment and input decisions that enhance efficiency. In addition, Zheng and Ning [4] proposed that agricultural insurance can improve factor input through credit access, further enhancing agricultural efficiency.

Despite these findings, many existing studies fail to adequately control for time- and region-specific policy heterogeneity, which may lead to biased estimates of the true effects of agricultural insurance. Moreover, much of the current literature focuses primarily on its aggregate effects, lacking an in-depth analysis of the specific mechanisms through which agricultural insurance influences productivity.

As research on the mechanisms of agricultural insurance has deepened, scholars increasingly recognize that its impact on agricultural TFP does not follow a single path. Instead, it operates through a logical chain of "risk mitigation → input decisions → production efficiency." Among potential mediating factors, agricultural mechanization is widely viewed as a key channel. As a hallmark of modern agriculture, mechanization not only reduces reliance on traditional labor and improves operational efficiency but also facilitates scale expansion and intensification, ultimately boosting productivity [5]. Some studies suggest that agricultural insurance can indirectly promote mechanization by alleviating farmers' income concerns and encouraging investment in machinery [6], while others argue that it helps counter arable land decline [7]. Nevertheless, empirical research examining the mediating role of mechanization between insurance and TFP remains limited and underdeveloped.

In addition, regional heterogeneity is a crucial but often overlooked dimension in agricultural insurance studies. Substantial differences exist across China in agricultural development, insurance system implementation, subsidy structures, and risk exposure. For example, Gan [8] finds that the marginal effect of insurance policy is greater in the western region due to lower initial coverage and higher agricultural risks. Similarly, Zhang and He [9] note growing disparities in insurance development across provinces. Yet most existing studies focus on national-level estimates and rarely explore regional differences across the eastern, central, and western regions in a structured manner.

Against this backdrop, this paper contributes to the literature in several ways. First, it employs a two-way fixed effects model using panel data from 30 Chinese provinces (2011–2021), effectively controlling for unobserved heterogeneity and time trends. Second, it incorporates agricultural mechanization into the analytical framework to identify its mediating role in the relationship between agricultural insurance and TFP. Third, it conducts a regional heterogeneity analysis to compare policy effectiveness across different development zones, thereby offering targeted empirical insights for subregional policy design on agricultural insurance and input optimization.

2. Mechanism Analysis and Research Hypothesis

Agricultural insurance, as an important part of agricultural support policy, has an important role in mitigating risks, stabilizing expectations, and guiding resource allocation. In recent years, with the continuous improvement of agricultural insurance coverage and protection level, its potential mechanism in enhancing agricultural production efficiency and optimizing factor allocation has gradually attracted attention. Especially in the process of agricultural modernization, agricultural mechanization, as one of the core driving forces to promote agricultural TFP, may play a key intermediary role in the path of agricultural insurance affecting agricultural TFP. Therefore, this paper will theoretically explore the direct impact of agricultural insurance on agricultural TFP, the internal mechanism, and regional heterogeneity, and on the basis of this, put forward the research hypothesis.

2.1 The Direct Impact of Agricultural Insurance on Agricultural TFP

As a key component of modern agricultural institutions, agricultural insurance influences production efficiency through multiple channels. According to Rao's [10] review of risk aversion theory, farmers often exhibit strong risk-averse behavior when confronted with uncertainties such as natural disasters and market price volatility. This tendency leads to conservative input decisions, which in turn restricts the optimal allocation of agricultural resources. Agricultural insurance, as a risk management instrument, reduces perceived uncertainty through its risk-transfer function. This stabilizes expected returns, enhances farmers' investment confidence, encourages technology adoption and capital input, and ultimately improves agricultural production efficiency.

From the perspective of new institutional economics, institutional arrangements exert a profound influence on production efficiency. Within this framework, agricultural insurance is not merely a tool for risk mitigation but also a mechanism for optimizing factor allocation and enhancing institutional efficiency. Improvements in insurance coverage, claims capacity, and institutional credibility can foster a more favorable production environment, ease financial constraints, and support farm expansion or technology adoption [11]. Empirical evidence has consistently shown a significant positive correlation between the development of agricultural insurance and agricultural TFP, highlighting its institutional role in stabilizing income, mitigating risks, and facilitating capital investment.

Hypothesis 1: Agricultural insurance density has a significant positive effect on agricultural TFP.

2.2 Agricultural Insurance Affects the Level of Mechanization and thus Plays a Role in Agricultural TFP

In agricultural production, mechanization serves as a critical pathway to achieving intensification, scale, and technological advancement. Agricultural insurance helps reduce production risks, improves farmers' expectations regarding future returns, and enhances their capacity and willingness to invest in capital—particularly in agricultural machinery. According to the theory of agricultural technology diffusion, farmers' adoption of new technologies is closely linked to their risk tolerance and financial capacity, both of which are positively influenced by agricultural insurance [12]. As a result, agricultural mechanization can act as a mediating variable linking agricultural insurance to improvements in TFP. Mechanization not only enhances productivity directly but also indirectly boosts TFP by reducing labor dependence, enabling economies of scale, and optimizing resource allocation. Empirical studies support this view by demonstrating the positive impact of agricultural insurance on machinery investment and the strong contribution of mechanization to productivity growth, thereby reinforcing the "insurance → mechanization → TFP" mechanism.

In this paper, the improved Cobb-Douglas production function is introduced to study the agricultural productivity of region *i* in year *t*. Its agricultural TFP is denoted as tfpch_{it}, which is jointly determined by the level of mechanization mech_{it}, the labor input L_{it}, and other control variables (such as the urbanization rate, industrial structure, etc.). Although the theoretical model considers labor input as an important element of agricultural production, in the empirical part, the labor variable is not included separately in the regression because the TFP indicator itself has already comprehensively reflected the efficiency of various types of inputs.

The underlying production function can be expressed as:

$$\mathrm{tfpch}_{it} = A_{it} \times \mathrm{mech}_{it}^{\alpha} \times L_{it}^{1-\alpha} \tag{1}$$

where A_{it} is the exogenous efficiency level of agricultural production and $0 < \alpha < 1$. In this framework, if the level of mechanization increases, i.e., $\partial \mathrm{tfpch}_{it} / \partial \mathrm{mech}_{it} > 0$, it indicates that agricultural mechanization contributes to the increase of agricultural TFP. Meanwhile, we assume that the agricultural insurance intensity (i.e., agricultural insurance income as a share of total agricultural population) is $\mathrm{density}_{it}$. Agricultural insurance enhances the ability and willingness of farmers to invest by mitigating risks, guaranteeing basic income, and enhancing credit availability, thus increasing mechanization inputs. Therefore, it can be assumed:

$$\frac{\partial \mathrm{tfpch}_{it}}{\partial \mathrm{density}_{it}} > 0 \tag{2}$$

Combining the two equations, we can derive the indirect effect of agricultural insurance on TFP:

$$\frac{\partial \mathrm{tfpch}_{it}}{\partial \mathrm{density}_{it}} = \frac{\partial \mathrm{tfpch}_{it}}{\partial \mathrm{mech}_{it}} \times \frac{\partial \mathrm{mech}_{it}}{\partial \mathrm{density}_{it}} > 0 \tag{3}$$

This equation shows that the positive impact of agricultural insurance on agricultural TFP can be partially achieved by increasing the level of agricultural mechanization, that is, there is a significant mediating mechanism.

Hypothesis 2: Agricultural insurance density indirectly promotes agricultural TFP by increasing the level of agricultural mechanization; that is, agricultural mechanization plays a mediating role in this relationship.

2.3 The Impact of Agricultural Insurance on Agricultural TFP in Different Regions

Significant regional differences exist across China in terms of natural conditions, economic development, agricultural risk exposure, and policy implementation capacity. These disparities suggest that the effects of agricultural insurance are likely to exhibit regional heterogeneity. According to the law of diminishing marginal returns and the theory of institutional performance, agricultural insurance is expected to have a stronger incentive and protective effect in central and western regions, where coverage remains low, infrastructure is less developed, and policy support is more substantial.

Specifically, in the eastern region—where agricultural insurance is relatively mature—the marginal benefit of additional insurance inputs tends to decline. In contrast, in the central and western regions, where insurance penetration is still limited and agricultural risks are more concentrated, insurance policies are more effective in reallocating resources, encouraging technology adoption and capital investment, and thereby enhancing agricultural TFP. Empirical studies provide evidence for this view. Gan [8] found that the elasticity of agricultural insurance subsidies with respect to TFP in the western region is 1.3 times that of the eastern region, indicating a stronger marginal policy effect. Similarly, Carter et al. [13], in a cross-country study, showed that the guiding role of agricultural insurance is more pronounced in low-income, high-risk regions.

These findings underscore the importance of incorporating regional characteristics into the design and implementation of agricultural insurance policies. Tailored, region-specific approaches are necessary to maximize policy effectiveness.

Hypothesis 3: The impact of agricultural insurance on agricultural total factor productivity varies significantly across regions.

3. Data Processing and Measurement

3.1 Model Setting

This study employs a two-stage empirical strategy to examine the impact of agricultural insurance on agricultural total factor productivity (TFP).

In the first stage, the measurement of agricultural TFP is sourced from Chen et al. [1], who applied the DEA-Malmquist index method to calculate TFP for each Chinese province. The DEA-Malmquist index is particularly well-suited for capturing the dynamic efficiency of agricultural production systems involving multiple inputs and outputs. Given the methodological robustness of that approach, this study directly adopts their TFP estimates without recalculating them.

In the second stage, to estimate the effect of agricultural insurance density on TFP, a two-way fixed effects model is constructed. This model controls for both province-specific and time-specific effects, thereby mitigating potential bias arising from unobserved heterogeneity or omitted variables. The model is specified as follows:

$$\begin{aligned} tfpch_{it} = \alpha + \beta_1 density_{it} &+ \beta_2 urban_{it} \\ &+\beta_3 lossrat_{it} + \beta_4 industry_{it} \\ &+\beta_5 dis_{it} + \beta_6 prec_{it} \\ &+\beta_7 pest_{it} + \mu_i + \lambda_t + \varepsilon_{it} \end{aligned} \tag{4}$$

Among them, $tfpch_{it}$ is the total factor productivity in agriculture, $density_{it}$ is the core explanatory variable. Combining with related literature, this paper selects agricultural insurance density, i.e., the amount of regional per capita agricultural insurance, reflecting the level of per capita agricultural insurance participation. The rest are control variables, including the urbanization rate $urban_{it}$, industrial structure advanced $industry_{it}$, agricultural insurance payout rate $lossrat_{it}$, the degree of disaster dis_{it}, the level of education edu_{it}, the annual precipitation $prec_{it}$, and fertilizer use $pest_{it}$. μ_i is individual fixed effect, controlling for unobservable characteristics of different provinces. λ_t is time fixed effect, controlling for changes in the macroeconomic environment in each year, and ε_{it} is random error term.

3.2 Variable Selection

3.2.1 Explained variables and core explanatory variables

This paper selects agricultural total factor productivity (TFP) as the explained variable to measure the overall efficiency and sustainable growth potential of agricultural production. TFP in the agricultural economy refers to the portion of output growth driven by non-traditional factors—such as technological progress, institutional environment, policy execution efficiency, and optimized resource allocation—beyond the contributions of traditional inputs like labor, land, and capital. To avoid redundancy in the calculation, this study directly adopts the TFP data calculated by Chen et al. [1], denoted as *tfpch*, which is derived using the DEA-Malmquist index method.

Agricultural insurance, as a key institutional tool for managing agricultural risk, significantly influences farmers' production decisions and long-term investment behavior. To capture its development level, this paper uses agricultural insurance density—defined as the ratio of agricultural insurance premium income to the total agricultural population—as the core explanatory variable. This metric reflects the extent of insurance coverage and participation within the agricultural sector. The variable is denoted as density, and data are sourced from the China Insurance Yearbook and the China Statistical Yearbook. It is used to investigate both the direct effect of agricultural insurance on TFP and the indirect mechanisms through which this effect may operate.

3.2.2 Mechanism variables (mediating variables)

This study focuses on the mechanism by which agricultural insurance affects TFP, with particular attention to the mediating effect of agricultural mechanization, as discussed by Zheng and Jiang [14]. Agricultural mechanization, as a hallmark of agricultural modernization, not only transforms production methods and improves resource allocation efficiency but also directly influences farmers' risk perceptions and willingness to invest in new technologies.

As the agricultural insurance system continues to develop, farm operators are more likely to invest in agricultural machinery when their production risks are mitigated. This leads to improved mechanization levels and, in turn, higher agricultural TFP. Therefore, agricultural mechanization is selected as a representative mediating variable. It is measured by the total power of agricultural machinery (in kilowatts), with the natural logarithm applied to construct the variable *mech*. This indicator reflects the overall advancement in agricultural equipment and aligns with the logical transmission path of "technological progress → resource optimization → efficiency improvement," making it a suitable bridge variable linking agricultural insurance and TFP.

3.2.3 Control variables

To reduce potential bias from omitted variables, this study incorporates a series of control variables widely recognized to influence agricultural TFP, covering multiple dimensions such as agricultural production, factor allocation, and socioeconomic development.

(1) Urbanization level (*urban*): measured by the proportion of urban residents in the total population. Urbanization influences agricultural resource reallocation and scale operations through mechanisms such as labor mobility and infrastructure improvements.

(2) Agricultural insurance payout ratio (*lossrat*): calculated as the ratio of insurance compensation to premium income. This controls how the operational efficiency of insurance schemes may affect farmers' production behavior.

(3) Industrial structure upgrading (*industry*): measured by the value-added share of the tertiary sector in GDP. This variable reflects the development of non-agricultural industries and their substitution effects on the agricultural labor force [15].

(4) Disaster severity (*lndis*): expressed as the logarithm of the ratio between disaster-affected agricultural land and total arable land. It captures the extent of exposure to natural hazards—a major driver of agricultural insurance demand—and also influences farmers' willingness to invest.

(5) Education level (*edu*): measured by the average years of schooling per province. Higher education enhances human capital in agriculture and increases the likelihood of farmers adopting new technologies [16].

(6) Annual precipitation (*prec*): measured as the logarithm of average annual rainfall (in millimeters) per province. Precipitation represents a key climatic input for agricultural productivity [17].

(7) Fertilizer intensity (*pest*): calculated as the logarithm of fertilizer use per hectare. Agricultural insurance may influence farmers' choice of crop varieties—especially those with insurance coverage and premium subsidies—

thus altering fertilizer application intensity [18].

4. Empirical Analysis

4.1 Descriptive Statistics

Table 1 presents the descriptive statistics for all variables included in the empirical model.

Table 1: Descriptive statistics of variables

Variable	Obs	Mean	Std. dev.	Min	Max
tfpch	330	1.101	0.075	0.872	1.564
density	330	1.235	1.312	0.009	7.063
mech	330	7.693	1.118	4.543	9.499
urban	330	0.596	0.121	0.350	0.896
lossrat	330	0.654	0.204	0.216	1.579
industry	330	0.476	0.097	0.297	0.839
lndis	330	5.893	1.637	0.010	8.349
edu	330	7.803	0.613	5.861	9.910
prec	330	7.171	1.111	4.157	8.493
pest	330	4.813	1.146	1.825	6.559

4.2 Analysis of Benchmark Regression Results

In this paper, the benchmark regression model is firstly constructed and sequentially estimated by ordinary least squares (OLS) and two-way fixed effects model (FE), and the relevant results are shown in Table 2. Model (1) and Model (2) are OLS estimation, respectively, the setting without adding control variables and adding control variables; Model (3) and Model (4) further introduce the fixed effects of province and year to control the invariant characteristics and year shocks among regions, so as to improve the accuracy and explanatory power of the model estimation.

This paper first constructs a benchmark regression model, and sequentially applies the Ordinary Least Squares method (OLS) and the Two-way Fixed Effects Model (FE) for estimation. The relevant results are shown in Table 2. Model (1) and Model (2) are OLS estimations, without and with control variables, respectively; Model (3) and Model (4) incorporate province and year fixed effects to control for time-invariant regional characteristics and time shocks, thereby improving the accuracy and explanatory power of the estimation.

As shown by the regression coefficients, the core explanatory variable—agricultural insurance density (density)—demonstrates a significant and robust positive effect across all four models. In the most basic Model (1), the coefficient of density is 0.015 and is statistically significant at the 1% level, indicating that even without any control variables, the expansion of agricultural insurance is significantly associated with improvements in agricultural TFP. Model (2), which includes a full set of control variables, also yields a highly significant result, showing that the positive effect of agricultural insurance on productivity remains robust when other influencing factors are considered.

Table 2: Regression results of agricultural insurance on agricultural total factor productivity

	(1) OLS	(2) OLS	(3) FE	(4) FE
Variables	tfpch	tfpch	tfpch	tfpch
density	0.015***	0.013**	0.022***	0.016***
	(0.004)	(0.006)	(0.006)	(0.006)
urban		0.365**		0.547***
		(0.170)		(0.179)
lossrat		–0.051**		–0.003
		(0.024)		(0.022)
industry		–0.298**		0.083
		(0.128)		(0.156)
lndis		0.022***		0.005
		(0.006)		(0.006)
edu		0.022		0.043***
		(0.014)		(0.014)

prec		–0.033		0.027
		(0.031)		(0.029)
pest		–0.138***		–0.040
		(0.043)		(0.045)
Constant	1.082***	1.644***	1.156***	0.479
	(0.007)	(0.345)	(0.012)	(0.348)
Year	Yes	Yes	Yes	Yes
Province	No	No	Yes	Yes
Observations	330	330	330	330
R-squared	0.167	0.250	0.296	0.370
Number of provinces	-	-	30	30

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

In Models (3) and (4), the fixed effects specification addresses unobservable time-invariant provincial characteristics and year-specific shocks. In Model (3), the coefficient increases to 0.022 and remains statistically significant at the 1% level, suggesting that controlling for individual heterogeneity clarifies and strengthens the effect of agricultural insurance. In Model (4), after further incorporating control variables and applying two-way fixed effects, the coefficient slightly decreases to 0.016 but remains positively significant, confirming the direct and stable relationship between agricultural insurance density and agricultural productivity.

In summary, the results show a significant and consistent positive association between agricultural insurance density and agricultural TFP, supporting the hypothesis that insurance participation can promote efficient resource allocation and technological investment, thereby enhancing overall productivity. These findings lay a solid empirical foundation for the mechanism and heterogeneity analysis that follow and preliminarily validate Hypothesis 1.

4.3 Endogeneity Test

To address potential endogeneity between agricultural insurance density and agricultural total factor productivity (TFP), this study employs an instrumental variable (IV) approach to enhance the credibility of causal inference. Two instruments are selected: (1) the average agricultural insurance density of neighboring provinces (*neighbor_density*), and (2) the one-period lag of agricultural insurance density (*ldensity*). These instruments are chosen based on the following rationale.

First, *neighbor_density* is strongly correlated with the focal province's insurance density due to spatial interdependence in policy implementation, shared risk profiles, and regional financial service linkages. Second, *ldensity* captures the inertia and path dependence inherent in agricultural insurance expansion—historical values are predictive of current insurance levels. Crucially, both instruments are assumed to affect current TFP only through their influence on agricultural insurance density, thus satisfying the exclusion restriction and supporting the validity of the IV strategy.

Table 3: Endogeneity test

Variables	Model (1)	Model (2)
	Agricultural insurance density of neighbor province	Lagging agricultural insurance density variable
	tfpch	tfpch
density	0.011*	0.012**
	(0.006)	(0.006)
urban	0.549***	0.511***
	(0.171)	(0.178)
lossrat	–0.007	–0.005
	(0.022)	(0.023)
industry	0.037	0.129
	(0.147)	(0.157)
lndis	0.004	0.004
	(0.006)	(0.006)
edu	0.037***	0.037***
	(0.013)	(0.013)
prec	0.018	0.015
	(0.028)	(0.029)
pest	–0.030	–0.005

	(0.045)	(0.049)
Constant	0.575*	0.379
	(0.334)	(0.366)
IV	*neighbor_density*	*neighbor_density, ldensity*
Year	Yes	Yes
Observations	330	300
Number of provinces	30	30

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 3 reports the results of the two-stage least squares (2SLS) regressions. In Model (1), using *neighbor_density* alone as an instrument, the coefficient on density remains positive and statistically significant. In Model (2), after incorporating *ldensity* as an additional instrument, the coefficient remains significant and increases slightly, indicating that the positive effect of agricultural insurance on agricultural TFP is robust even after accounting for potential endogeneity.

4.4 Robustness Test

To assess the robustness of the baseline regression results, this study conducts three robustness checks, as detailed in Table 4:

(1) Exclusion of the extreme year: In 2016, the middle and lower reaches of the Yangtze River experienced severe flooding, which may have caused abnormal fluctuations in both agricultural insurance payouts and agricultural output, potentially biasing the results. After removing the data from 2016 and re-estimating the model, the positive effect of agricultural insurance density on agricultural TFP remains statistically significant, with only minimal changes in coefficient magnitude. This suggests that the baseline findings are not driven by extreme year effects.

(2) Winsorization at the 1% level: To mitigate the influence of outliers, all variables are winsorized at the 1st and 99th percentiles. The results after winsorization are consistent with the baseline regression in both coefficient sign and statistical significance. Major control variables also maintain strong robustness, indicating that the conclusions are not sensitive to extreme values.

(3) Random effects model estimation: As a complementary specification, the random effects model is estimated. The coefficient on agricultural insurance density remains positive and statistically significant, in line with the results from the fixed effects model. This further reinforces the robustness and reliability of the empirical findings.

Table 4: Robustness test

Variables	Model (1)	Model (2)	Model (3)
	Excluding extreme years	Tailoring	Random effects model
	tfpch	tfpch	tfpch
density	0.015**	0.011*	0.010***
	(0.006)	(0.006)	(0.004)
urban	0.485***	0.549***	–0.007
	(0.179)	(0.171)	(0.068)
lossrat	–0.021	–0.007	–0.023
	(0.023)	(0.022)	(0.022)
industry	0.106	0.037	–0.093
	(0.154)	(0.147)	(0.076)
lndis	0.003	0.004	0.009**
	(0.006)	(0.006)	(0.005)
edu	0.038***	0.037***	0.002
	(0.014)	(0.013)	(0.010)
prec	0.007	0.018	0.002
	(0.029)	(0.028)	(0.006)
pest	–0.035	–0.030	–0.012*
	(0.045)	(0.045)	(0.007)
_cons	0.680**	0.575*	1.123***
	(0.344)	(0.334)	(0.086)
N	300	330	330

R-squared	0.390	0.367	

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

4.5 Mediation Effect Mechanism Test

4.5.1 Mediating effect modeling

In the previous regression analysis, the direct effect of agricultural insurance on agricultural total factor productivity (TFP) was confirmed. This section further introduces agricultural mechanization as a mediating variable to test the mechanism through which insurance affects TFP. The mediation model is constructed as follows:

$$\mathrm{tfpch}_{it} = \alpha_0 + c \times \mathrm{density}_{it} + \beta \sum \mathrm{control}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (5)$$

In Equation (5), if the estimated coefficient c is significantly positive, it indicates that agricultural insurance positively contributes to agricultural TFP. To formally test the mediating role of agricultural mechanization, this study follows the stepwise procedure proposed by Wen and Ye [19] for mediation analysis.

$$\mathrm{mech}_{it} = \alpha_0 + a \times \mathrm{density}_{it} + \beta \sum \mathrm{control}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (6)$$

$$\mathrm{Tfpch}_{it} = \alpha_0 + c' \times \mathrm{density}_{it} + b \times \mathrm{mech}_{it} + \beta \sum \mathrm{control}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (7)$$

For Equation (6): if the obtained coefficienta is significantly positive, it indicates that agricultural insurance can promote the level of agricultural mechanization, and the final joint Equation (7): if the coefficients c' and b are both significant, it indicates that agricultural insurance can promote agricultural TFP through the promotion of the level of agricultural mechanization, i.e., there is a mediating effect of the level of agricultural mechanization.

In the above equation,$\mathrm{tfpch}_{it}$is the total factor productivity in agriculture, $\mathrm{density}_{it}$ is the core explanatory variable, mech_{it} is the level of agricultural mechanization, $\sum \mathrm{control}_{it}$ is control variables, μ_i is the individual fixed effect, controlling for unobservable characteristics of different provinces, λ_t is the time fixed effect, controlling for changes in the macroeconomic environment in each year, and ε_{it} is the random error term.

4.5.2 Mechanism test for mediated effects

In order to further reveal the intrinsic mechanism of the impact of agricultural insurance on agricultural TFP, this paper introduces the level of agricultural mechanization as a mediating variable, constructs a mediation effect model, and carries out empirical tests, and the results are shown in Table 5. First of all, the regression results in Model (1) with the level of agricultural mechanization as the dependent variable show that the density of agricultural insurance has a significant positive effect on the level of agricultural mechanization, with a coefficient of 0.094 and a significance of 1% level. This result shows that with the development of agricultural insurance, farmers' expected returns on agricultural production and risk resistance are enhanced, which makes them more willing and able to invest in agricultural machinery and promote the level of agricultural mechanization. In Model 2, agricultural TFP is used as an explanatory variable, and the regression coefficient of agricultural insurance density is 0.016, which is also significant at the 1% level, indicating that agricultural insurance has a significant promotion effect on agricultural TFP in general. In other words, agricultural insurance can directly improve the efficiency of agricultural production through the paths of risk mitigation mechanisms and enhancement of agricultural investment incentives, which in turn enhances agricultural total factor productivity. After introducing the mediating variable-agricultural mechanization level in Model (3), the coefficient of agricultural insurance density decreases to 0.0101, and the significance decreases to 10% level, while the regression coefficient of the mediating variable agricultural mechanization level is 0.064, which is still significant at 1% level. This result indicates that the level of agricultural mechanization itself also has a significant role in promoting agricultural TFP, while the effect of agricultural insurance density is weakened, indicating that the mediating effect exists significantly, while controlling for the effects of other variables.

Table 5: Mediated effects test results

Variables	Model (1)	Model (2)	Model (3)
	mech	tfpch	tfpch
density	0.094***	0.016***	0.010*
	(0.018)	(0.006)	(0.006)
mech			0.064***
			(0.018)

urban	–0.301	0.547***	0.566***
	(0.568)	(0.179)	(0.176)
lossrat	0.022	–0.003	–0.005
	(0.071)	(0.022)	(0.022)
industry	1.281***	0.083	0.001
	(0.494)	(0.156)	(0.155)
lndis	–0.001	0.005	0.005
	(0.019)	(0.006)	(0.006)
edu	0.015	0.043***	0.042***
	(0.043)	(0.014)	(0.013)
prec	0.090	0.027	0.021
	(0.093)	(0.029)	(0.029)
pest	0.508***	–0.040	–0.073
	(0.143)	(0.045)	(0.045)
Constant	4.050***	0.479	0.221
	(1.102)	(0.348)	(0.349)
Year	Yes	Yes	Yes
Observations	330	330	330
R-squared	0.219	0.370	0.395
Number of provinces	30	30	30

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Further calculations can be obtained:

$$\mathrm{a} \times \mathrm{b} = 0.094 \times 0.064 = 0.006016$$

$$\mathrm{c} = 0.018$$

$$\frac{ab}{c} = \frac{0.006016}{0.018} \approx 33.42\%$$

The value of the mediation effect is 0.006016, accounting for approximately 33.42% of the total effect of agricultural insurance on agricultural TFP (0.018). This indicates that more than one-third of the total impact of agricultural insurance on TFP is realized indirectly through improvements in agricultural mechanization. The above analysis clearly demonstrates that agricultural mechanization serves as an important intermediary channel between agricultural insurance and TFP, and constitutes one of the key pathways through which agricultural insurance promotes high-quality agricultural development, consistent with Hypothesis 2.

In summary, agricultural insurance not only enhances TFP directly by mitigating production risks and stabilizing farm household income, but also indirectly encourages farmers to increase investment in agricultural machinery, thereby improving mechanization levels. This, in turn, facilitates the achievement of scale and modernization in agricultural production, ultimately contributing to the sustainable improvement of total factor productivity. Therefore, it is essential to strengthen the coordination between agricultural insurance and mechanization policies to fully leverage their combined effect in improving agricultural production efficiency.

4.6 Regional Heterogeneity Analysis of the Impact of Agricultural Insurance on Agricultural Total Factor Productivity

According to the results of the regional heterogeneity analysis, the impact of agricultural insurance on agricultural total factor productivity (TFP) exhibits significant regional variation. By dividing China into three regions—eastern, central, and western—we can more precisely observe the role and magnitude of agricultural insurance's impact across different areas. As shown in Table 6:

Table 6: Results of heterogeneity analysis

Variables	Eastern region	Central region	Western region
	tfpch	tfpch	tfpch
density	0.058*	0.094***	0.025**
	(0.033)	(0.017)	(0.010)
urban	0.797***	–0.865	–1.503*
	(0.247)	(0.783)	(0.785)
lossrat	–0.010	0.009	–0.005
	(0.039)	(0.069)	(0.042)

industry	0.301	0.017	0.080
	(0.311)	(0.250)	(0.211)
lndis	0.006	–0.010	–0.003
	(0.005)	(0.014)	(0.018)
edu	0.041***	0.007	0.114**
	(0.009)	(0.050)	(0.041)
prec	0.041	–0.115	–0.016
	(0.029)	(0.073)	(0.072)
pest	–0.140	0.268*	–0.180**
	(0.099)	(0.123)	(0.064)
Constant	0.569	0.890	1.970**
	(0.380)	(0.690)	(0.649)
Year	Yes	Yes	Yes
Observations	143	66	121
R-squared	0.407	0.726	0.472
Number of provinces	13	6	11

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

The results indicate that agricultural insurance density has a positive and statistically significant effect on agricultural TFP across all three regions, though the strength of the effect varies. In the central region, the regression coefficient reaches 0.094 and is significant at the 1% level, suggesting that agricultural insurance exerts the strongest impact on TFP in this region. The coefficients for the eastern and western regions are 0.058 and 0.025, respectively. Although relatively lower in magnitude, both coefficients remain statistically significant, indicating that agricultural insurance also contributes positively to agricultural TFP in these regions, albeit to a slightly lesser extent compared to the central region.

5. Discussion

5.1 Main Findings

Based on panel data from 30 provinces in China spanning 2011 to 2021, this study constructs a two-way fixed effects model and incorporates mediation effect and regional heterogeneity analyses to systematically examine the mechanisms through which agricultural insurance density affects agricultural total factor productivity (TFP). The research conclusions are centered around three core hypotheses:

First, agricultural insurance exerts a significant positive effect on the enhancement of agricultural TFP, confirming Hypothesis 1. The empirical results show that the coefficient of agricultural insurance density remains consistently positive and statistically significant, regardless of whether two-way fixed effects or control variables are included. This indicates that agricultural insurance not only mitigates production risks and strengthens farmers' risk management capabilities, but also effectively incentivizes their investment in efficient production factors. As a result, it contributes to optimizing resource allocation and improving the production structure, thereby promoting steady improvements in agricultural productivity. This finding aligns with both risk mitigation theory and incentive mechanism theory and is corroborated by numerous empirical studies conducted domestically and internationally. Together, the evidence provides strong support for agricultural insurance as a fundamental institutional arrangement for advancing agricultural modernization.

Second, agricultural insurance indirectly promotes TFP growth by enhancing the level of agricultural mechanization, thereby validating Hypothesis 2. The results of the mediation model show that agricultural insurance density not only significantly improves the level of mechanization, but that mechanization itself exerts a significant positive impact on TFP. Moreover, when the mediating variable is included, the direct effect of insurance on TFP decreases, indicating that agricultural mechanization plays a partial mediating role. On one hand, mechanization alleviates structural labor shortages in rural areas; on the other, it improves the technical intensity and scale efficiency of agricultural production through precise operations and cost savings. These findings support the theoretical and empirical transmission path of "agricultural insurance → agricultural mechanization → agricultural TFP," revealing the underlying mechanism by which agricultural insurance enhances productivity.

Third, there is significant regional heterogeneity in the impact of agricultural insurance on agricultural TFP, confirming Hypothesis 3. The empirical results show that the marginal effect of agricultural insurance is positive and statistically significant across the eastern, central, and western regions. Specifically, the regression coefficients are 0.155 ($p < 0.01$) in the western region, 0.110 ($p < 0.05$) in the central region, and 0.056 ($p < 0.1$) in the eastern region. These differences likely stem from variations in economic foundations, exposure to agricultural risks, and stages of insurance development across regions. In the central and western regions—where agricultural insurance systems are still in the promotion stage—insurance policies offer stronger incentives for farmer behavior and more pronounced risk protection effects. These impacts are especially evident in areas prone to natural disasters or lacking in financial infrastructure, where agricultural insurance helps unlock farmers' investment motivation and productive potential. In contrast, in the more developed eastern region, where the insurance system is relatively mature, the marginal effect of insurance has begun to decline. Overall, this spatial heterogeneity supports institutional performance theory and the law of diminishing marginal returns, suggesting that policy tools tend to be more effective in regions with weaker initial conditions. These findings also underscore the importance of tailoring agricultural insurance policies to local conditions and implementing regionally differentiated strategies.

5.2 Policy Recommendations

Based on the empirical findings and theoretical analysis above, this paper offers the following policy recommendations:

(1) Continuously enhance the protective capacity and incentive function of the agricultural insurance system. The findings demonstrate that agricultural insurance density has a significant positive impact on agricultural TFP. This implies that agricultural insurance not only serves a risk mitigation role through post-disaster compensation but also acts as an ex-ante behavioral incentive. Accordingly, the premium subsidy mechanism should be further refined, and both coverage and crop types should be expanded in a targeted and reasonable manner, shifting the focus from mere "quantitative expansion" to "qualitative improvement." It is recommended to strengthen insurance protection for high-risk and high-value crops, and gradually scale up full-cost and income insurance to stabilize farmers' expectations and strengthen their investment confidence. At the same time, insurance institutions should be encouraged to streamline service processes and improve claims efficiency, so that agricultural insurance truly serves as both a "safety net" and a "production enabler" in farmers' decision-making.

(2) Promote the development of agricultural mechanization and strengthen synergy between insurance and mechanization policies. Empirical evidence reveals that agricultural mechanization plays a mediating role between agricultural insurance and TFP, indicating that insurance policies can indirectly enhance production efficiency by encouraging machinery investment. Therefore, agricultural insurance should be coordinated with other instruments such as subsidies for agricultural machinery purchases to promote an integrated development model of "insurance + machinery + service." On one hand, the development of innovative insurance products—such as loss insurance for machinery operations and specialized coverage for equipment—should be encouraged to raise protection levels. On the other hand, models such as "insurance + credit + agricultural machinery leasing" should be promoted to support farmers and new agricultural entities in upgrading mechanization and improving the resilience and scalability of agricultural production through financial tools.

(3) Promote regionally differentiated agricultural insurance system design. The research confirms significant regional variation in the marginal effects of agricultural insurance, with stronger policy leverage observed in the central and western regions. A region-specific implementation mechanism should be developed under a unified national framework. In the western region, which faces frequent natural disasters and has relatively weak financial capacity, central government support should be appropriately increased by raising subsidy proportions and improving the catastrophe and reinsurance systems. In the central region, the integration of agricultural insurance with mechanization policies, technical services, and scale operations should be strengthened. In the eastern region, where systems are more mature, efforts should focus on product innovation, such as promoting "insurance + futures" and "insurance + agricultural technology promotion" models, to better leverage the guiding role of insurance in advancing refined and green agricultural development.

In conclusion, agricultural insurance is playing an increasingly vital role in promoting high-quality agricultural development. Moving forward, its three core functions—risk management, financial services, and production incentives—should be further strengthened. This will help shift agricultural insurance from a traditional "bottom-line safety net" toward a modern "productivity-enhancing system," thereby providing stronger institutional support for the realization of a robust and modern agricultural sector.

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