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EDITED BY
Wenjin Long,
China Agricultural University, China

REVIEWED BY
Ming Gao,
Research Center for Rural Economy, China
Wei Tengda,
Ministry of Agriculture and Rural Affairs of the People's Republic of China, China

*CORRESPONDENCE
Hong-xing Wen
hxwen2011@126.com
Xiao-qing Wu
xqwu0717@126.com

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Agricultural agglomeration or industrial integration: how does agricultural insurance bolster agricultural resilience in China?

Chen Xie[1], Yuan-pei Kuang[1], Hong-xing Wen[2]* and Xiao-qing Wu[2]*

[1]School of Economics, Hunan Agricultural University, Changsha, China, [2]School of Business, Hunan Agricultural University, Changsha, China

Agricultural insurance has achieved rapid development in China, but its role in enhancing agricultural resilience remains unclear. This article aims to fill this research gap by investigating the impact and mechanism of agricultural insurance on agricultural resilience from the perspectives of agricultural agglomeration and industrial integration. The empirical results demonstrate that agricultural insurance exerts a significant and positive influence on the resilience of agriculture, which remains valid even after accounting for endogenous factors through the application of two IV sets. Further mechanism analysis reveals that agricultural insurance primarily boosts agricultural resilience by encouraging horizontal agricultural agglomeration rather than vertical industrial integration. Nevertheless, the influence of agricultural insurance on agricultural resilience differs among regions. Specifically, its effect on agricultural resilience is markedly more pronounced in the eastern and central regions compared to the less-developed western regions. Moreover, its effect on the agricultural resilience in the main grain-producing areas is obviously stronger than that in the main grain-selling area and those with a balance between production and marketing.

KEYWORDS

agricultural agglomeration, industrial integration, agricultural resilience, sustainable agricultural systems, agricultural insurance

1 Introduction

Agricultural resilience refers to the resistance, adaptability and resilience of agricultural systems to natural and anthropogenic stresses. However, as global temperatures rise and extreme weather events increase, agricultural systems are facing significant climate challenges. For example, the growth cycle, yield, and quality of crops are threatened by extreme weather conditions, posing a serious threat to the global food supply chain and food security. In addition, land degradation and loss of biodiversity have had irreversible negative impacts on the resilience of agricultural systems. The resilience of agricultural system not only involves the livelihoods, wellbeing and future sustainability of rural residents (Mijatović et al., 2013), but is also closely linked to the Sustainable Development Goals (SDGs) of hunger eradication, health and wellbeing, poverty eradication, and climate action globally. Improving agricultural resilience is therefore critical to the realization of the sustainable development agenda.

Agricultural insurance is widely recognized as one of the policy tools to improve agricultural resilience (Cole and Xiong, 2017). For example, agricultural insurance can help farmers reduce losses and agricultural business risks when facing natural disasters and market fluctuations, enhancing their ability to withstand external shocks (Hao and Tan, 2022). The risk sharing function of agricultural insurance also helps to increase the investment confidence of farmers (Quentin et al., 2022). This not only motivates farmers to adjust and resume production promptly (Hao and Tan, 2022), but also encourages sustainable farming practices by enabling them to invest in long-term improvements, such as the adoption of new technology, soil conservation, and crop diversification (Akinrinola and Okunola, 2014; Podbiralina et al., 2020). Moreover, agricultural insurance can also optimize the allocation of production factors (Zhang et al., 2018), thereby fostering large-scale production and specialized division of labor (Zou et al., 2022; Quan et al., 2024). Specialization is bound to bring about the evolution of agricultural industry organization (Qian, 2004). During the evolution process of China's agricultural industrialization, two mainstream industrial organization models have been roughly formed (Sun, 2005). The first organizational mode is vertical integration. That is, with the agricultural business subject as the center, connecting the upstream and downstream enterprises within the industry chain, which forms the integration of agriculture with the secondary industry and the tertiary industry (Zhao et al., 2017). The second organizational mode is horizontal agglomeration. This involves creating specialized and intensive industrial clusters or enterprise networks as the primary structure to achieve scale economies and external economies (Marshall, 1980; Cojanu and Pîslaru, 2012), where various dispersed and independent agricultural business entities are brought together to enter the market collectively. This results in the formation of industrial agglomeration within the agricultural sector (Sun, 2005). This article suggests that agricultural insurance enhances agricultural resilience by promoting industrial agglomeration within the agricultural sector and by encouraging industrial integration between the agricultural sector and other sectors. However, the relative importance of these two pathways remains undetermined.

The objective of this study is to identify the principal mechanism through which agricultural insurance enhances agricultural resilience, by comparing the following two pathways: (i) Horizontal agricultural agglomeration, which follows the sequence "Agricultural insurance→ Horizontal agglomeration within the agricultural sector→ Agricultural resilience", and (ii) Vertical industrial integration, which traces the path "Agricultural insurance→ Vertical integration between agriculture and other industries→ Agricultural resilience". Our motivation to clarify the above mechanism stems from two aspects. On the one hand, it involves enhancing the academic understanding of how agricultural insurance can resist and adapt to risk shocks by fostering the restructuring of industrial organizations. On the other hand, it aims to enrich insights for policymakers and practitioners into the interplay between insurance policy and industrial policy, thereby developing more targeted and effective policy interventions to synergistically promote the building of agricultural resilience.

Our study contributes to the existing literature in twofold. Firstly, we bridge the knowledge gap by providing empirical evidence that agricultural insurance enhances agricultural resilience, from the perspective of industrial organization structure. Secondly, our study presents a novel finding, indicating that agricultural insurance primarily enhances agricultural resilience by fostering industrial agglomeration within the agricultural sector, rather than by promoting industrial integration between agriculture and other sectors. This insight enriches our understanding of the underlying mechanisms through which agricultural insurance improves agricultural resilience.

The outline of this article is as follows. Section 2 offers a literature review. Section 3 outlines the theoretical framework and main hypotheses. Section 4 details the empirical strategy and data utilized. Section 5 presents the empirical results. Section 6 summarizes our conclusions and explores potential policy implications.

2 Literature review

2.1 Definition and measurement of resilience

The concept of resilience was originally introduced from the field of physics, and its connotation has undergone two complete expansions, evolving from engineering resilience to ecological resilience, and subsequently to evolutionary resilience. Engineering resilience pertains to the capacity of a system to revert to its original state following deformation by external forces (Holling, 1973). This concept underscores that the system possesses a single steady state and relies on the velocity of recovery to the initial state once the disturbance has ceased (Berkes and Folke, 1988). While ecological resilience emphasizes that a system can exist in multiple states of equilibrium, which may not only allow the system to return to its original state of balance but also enable it to establish a new equilibrium state. Thus, ecological resilience reflects the ability of a system to absorb maximum impact before altering its structure and function, transitioning into another equilibrium state (Holling, 1996). Although ecological resilience is more comprehensive than engineering resilience, it still adheres to the traditional view of equilibrium theory. Considering the dynamic evolution of the social-economic system, evolutionary resilience emphasizes that resilience should not be misconstrued as a return to the original state. Rather, it signifies the ability to change, adapt, and transform (Walker et al., 2004). Consequently, evolutionary resilience discards the equilibrium perspective, emphasizing the system's dynamic and uneven evolution, and places greater emphasis on the system's adaptability and transformability to adjust its structure in response to shock disturbances.

As the comprehension of resilience grows, it has led to the emergence of a variety of new concepts, such as urban resilience, household resilience, and industry resilience. Within mainstream literature, both family resilience and industry resilience are categorized under economic resilience. Household resilience is typically defined in accordance with the poverty trap theory as the ability of families to avoid poverty for a period of time in the face of various pressures and shocks (Barrett and Constas, 2014; Ciss and Barrett, 2018). While industry resilience pertains to the capacity of the industrial system to resist external shocks, recover rapidly from the shocks, and transform to a new growth path through the adjustment of organizational structure (Hao and Tan, 2022).

Clearly, household resilience emphasizes the capacity to recover and maintain balance, aligning with the equilibrium perspective of both engineering and ecological resilience; Industry resilience draws on the dynamic disequilibrium concept of evolutionary resilience, emphasizing not only the ability to resist and recover but also to reengineer adaptability and transformability. Since the city is a complex system comprised of both material systems and human communities (Godschalk, 2003), urban resilience is usually composed of four parts: infrastructure resilience, institutional resilience, economic resilience and social resilience (Jha et al., 2013).

Agricultural resilience discussed in this article falls under the category of industrial resilience. Urruty et al. (2016) described agricultural resilience from four perspectives: stability, robustness, vulnerability, and resilience. However, shocks frequently alter socio-economic variables, making it challenging for the system to sustain or revert to its original state. In reality, the system will undergo continuous, non-deterministic, and non-linear changes over time, reflecting its capacity to adapt to the risks associated with complex dynamics. Thus, Douxchamps et al. (2017) evaluated the climate resilience of agricultural systems across three dimensions: absorptive, adaptive, and transformative. Hao and Tan (2022) indicated that agricultural resilience consists of three components: resistance (depicting the robustness of agricultural system), restoration (reflecting the flexibility and speed of recovery of agricultural system after loss), and reengineering force (emphasizing the transformation of agricultural system post-shock). Vroegindewey and Hodbod (2018) defined the resilience of agricultural value chains as their ability to continue and develop their capacity to provide food security and other services in the face of disruptions by preparing for, responding to and recovering from unexpected shocks; avoiding tipping points; and adapting to ongoing changes.

Given that the connotations and measurements of agricultural resilience are not entirely consistent among different scholars, it is necessary to clarify the three fundamental concepts of agricultural resilience. Firstly, agricultural resilience is a capacity, not an outcome, which underscores the significant distinction between agricultural resilience and agricultural vulnerability (Hao and Tan, 2022). Secondly, agricultural resilience should not be misunderstood as reverting to the original state; rather, it should emphasize the ability of the agricultural system to withstand shocks through organizational restructuring, to recover swiftly from these shocks, and to continue achieving sustainable development along a new growth trajectory (Walker et al., 2004; Hao and Tan, 2022). Thirdly, agricultural resilience pertains to the entire agricultural system, encompassing the resilience of agricultural production, agricultural economy, and agricultural ecology as defined in prior literature (Zhao and Xu, 2023; Hao and Tan, 2022; Ling and Zhao, 2024).

2.2 The role of industrial organization structure in enhancing agricultural resilience

The first category of literature examines the impact of agricultural agglomeration on agricultural resilience (Sun and Jiao, 2024). Doronina et al. (2016) claimed that agro-industrial clustering can improve the competitiveness of rural areas and to some extent prevent regional impoverishment. Ding (2023) found that agricultural agglomeration in a specific region would increase farmers' income. However, they focus on emphasizing the significance of agricultural agglomeration for the economic resilience of the agricultural system, lacking direct evidence regarding the overall resilience of the entire agricultural system.

The second category of literature focuses on impact of industrial integration on agricultural resilience. The integration of agriculture, industry, and the service sector—commonly referred to as the three-industry integration—is the inevitable trend of modern agricultural development (Li and Long, 2024). This integration also represents the inevitable outcome of the evolution of industrial organization within the context of agricultural industrialization. A multitude of studies have indicated that industrial integration can infuse new vitality into the agricultural system. This includes facilitating an increase in agricultural incomes, reducing agricultural production and transaction costs, optimizing the agricultural industrial structure, and enhancing the efficiency of factor allocation within the agricultural production and management system (Wang and Li, 2019; Cao and Nie, 2021; He and Yang, 2021). Although these factors are key aspects of enhanced agricultural resilience, they do not offer direct evidence that industrial convergence can enhance agricultural resilience. To our knowledge, only a few articles have made seminal contributions in this regard. For instance, Hao and Tan (2022), Yin and Xiong (2024), and Zhou et al. (2023) indicated that industrial integration contributes to enhancing agricultural resilience, primarily by fostering rural economic growth, accelerating the accumulation of human capital, and promoting agricultural technology innovation and industrial structure adjustment.

2.3 The role of agricultural insurance in enhancing agricultural resilience

Regarding agricultural economic resilience, existing research has demonstrated that the risk compensation mechanism of agricultural insurance can effectively mitigate the adverse effects of disasters on agricultural economic system. This includes prevent farmers from experiencing impoverishment or falling back into poverty (Zhao et al., 2017; Zhu and Jiang, 2019), promote large-scale agricultural production, adjust the agricultural industrial structure, and raise agricultural total factor productivity, thus enhancing agricultural economic resilience (Zhang and Jiao, 2022; Quan et al., 2024). In terms of agricultural production resilience, studies have found that agricultural insurance can, on the one hand, motivate agricultural inputs by reducing risk and providing subsidies (Yu and Sumner, 2018), as well as promote the adoption of agricultural technology (Tang et al., 2019). On the other hand, it can also expand the scale of agricultural production by increasing labor productivity and arable land per capita, and encouraging specialization (Zou et al., 2022; Quan et al., 2024). It appears that only Ling and Zhao (2024), Xie et al. (2023), and Zhou et al. (2023) empirically examined the role of agricultural insurance in enhancing agricultural production resilience, but did not delve into the underlying mechanisms. With respect to agricultural ecological resilience, there is no direct evidence to support the role of agricultural insurance in enhancing it, and there is a clear discrepancy between the indirect evidence. Studies have shown that agricultural insurance can promote the innovation and adoption of green technology, thereby reducing agricultural carbon emissions and enhancing agricultural green total factor productivity (Fang et al., 2021; Jiang et al., 2023; Jin et al., 2024). However, Hou and Wang (2022) concluded that agricultural insurance exerts an inhibitory effect on green development in China. After enrolling in agricultural insurance, there was a significant increase in the use of fertilizer during the production process (Zhang et al., 2023).

Based on the aforementioned literature review, several consensus can be identified. Firstly, agricultural insurance, as a vital method for dispersing agricultural risks, is considered an effective tool for enhancing agricultural resilience; however, the direct empirical evidence supporting this is insufficient. Secondly, both agricultural agglomeration and industrial integration have been demonstrated to be significant factors in improving industrial resilience. Nevertheless, it remains unclear which path of industrial organization evolution that agricultural insurance facilitates to enhance agricultural resilience. This study aims to address the aforementioned research gap.

3 Theoretical framework

3.1 Agricultural insurance enhances agricultural resilience by promoting agricultural agglomeration

Since the 1990s, with the rise of economic globalization, cooperation between enterprises has become increasingly common. This shift has transformed the industrial organization structure from the traditional paradigm of "monopoly-competition" to the new paradigm of "competition-cooperation". This kind of enterprises, which both compete and cooperate within the same industry, have gathered in a specific geographical area, forming the phenomenon of industrial agglomeration. Utilizing the SCP (Structure-Conduct-Performance) analysis framework, this study aims to clarify how agricultural insurance can promote agricultural agglomeration by modifying market structure and influencing the conduct of market participants, and ultimately improving the resilience of the agricultural system.

Firstly, agricultural insurance can promote the aggregation of agricultural industries by optimizing the market structure. On the one hand, agricultural insurance disperses the risks associated with natural disasters and price fluctuations (Li and Wang, 2022), thereby lowering the entry barriers for various agricultural business entities, including cooperatives, specialized farms, and agricultural science and technology enterprises. This would guide the concentration of various agricultural business entities toward dominant areas with low risk, fostering a geographical agglomeration effect. On the other hand, by stabilizing the income expectations, agricultural insurance can also attract similar agricultural business entities to cluster in specific areas covered by insurance. This would enhance regional specialization levels, forming a "core-periphery" industrial chain network with complementary functions. For example, in Shouguang City, under the leadership of large agricultural enterprises, over 5,000 enterprises, cooperatives, and specialized farms have been attracted to gather together through organizational models such as "insurance + order agriculture/contract farming," forming a national vegetable price formation center in China.

Secondly, agricultural insurance can promote the agglomeration of agricultural industries by adjusting the conduct of market participants. On the one hand, the risk-sharing function of agricultural insurance motivates policyholders to commit more to dedicated investments aimed at long-term improvements, such as adopting new varieties and technologies, purchasing smart farm machinery, conserving soil, and diversifying crops (Akinrinola and Okunola, 2014; Podbiralina et al., 2020). This aids in accelerating the adoption and diffusion of advanced technology (Tang et al., 2019), producing a technology spillover effect, and fostering more favorable knowledge location advantages for the agglomeration of agricultural industries. On the other hand, to minimize compensation rates, insurance companies often employ technicians to provide professional technical guidance to policyholders throughout the entire process, from prenatal to postpartum care. This includes aiding them in making informed input decisions, enhancing risk prediction and management, and integrating market information. This aids dispersed farmers in forming specialized cooperatives or other industrial organizations, thereby creating convenient conditions for them to enter the agricultural cluster collectively, and thus enhancing the industrial concentration of the agricultural sector.

Thirdly, agricultural agglomeration can contribute to the enhancement of agricultural resilience. According to the theory of industrial agglomeration, enterprises within a cluster can benefit from external economies and scale economies by sharing infrastructure, a labor pool, and technology spillovers. This results in lower unit production costs and increased production efficiency. Furthermore, enterprises within the cluster significantly shorten the supply chain by localizing the industrial chain. This not only helps to avoid systemic interruptions caused by uncertainties and shocks but also enhances the speed of recovery post-disaster. Finally, within the cluster, various types of agricultural business entities can easily form cooperative networks and interest communities with complementary functions. When one link is impacted, others can swiftly substitute, thereby significantly enhancing the risk resistance, recovery, and adaptability of the agricultural cluster.

3.2 Agricultural insurance enhances agricultural resilience by promoting industrial integration

In the present study, industrial integration refers to the vertical integration of the primary, secondary, and tertiary industries, achieved by centering on the agricultural sector and expanding the upstream and downstream links of the industrial chain. Although the factors determining the vertical integration of the agricultural sector with other sectors are complex, transaction costs and contractual relationships play a crucial role (Williamson, 1985, 1996; Wan, 2008). From the perspectives of transaction cost theory and incomplete contract theory, this study aims to clarify how agricultural insurance can promote industrial integration by reducing transaction costs and restructuring the contractual relationships of cross-industry cooperation, and ultimately improving the resilience of the agricultural system.

Firstly, agricultural insurance can promote industrial integration by reducing transaction costs in cross-industry cooperation. Specifically, agricultural insurance alleviates the risk of contract performance due to natural disasters and price volatility, thereby reducing transaction costs (such as supervision costs and default risk) for industrial and service enterprises involved in agricultural investment. This facilitates the forward integration of industrial and service enterprises into the upstream agricultural sector, through the establishment of risk-sharing mechanisms. For instance, Alibaba has established 185 smart agricultural villages in China, characterized by the vertically integrated model of "supermarket + e-commerce + logistics + farm". They established a national agricultural big data platform through insurance technology innovation, such as utilizing remote sensing technology to determine damage and employing blockchain to trace agricultural products back to their origin. This enables logistics and e-commerce enterprises to reverse control agricultural production bases via data sharing. In Brazil, ethanol companies have established a closed-loop integration of the "farm-factory-energy network" through "agricultural insurance + futures hedging".

Secondly, agricultural insurance can foster industrial integration by restructuring the contractual relationships of cross-industry cooperation. The long periodicity of agricultural production and environmental uncertainty lead to naturally incomplete contracts (Hart and Moore, 1990). Agricultural insurance bridges this contractual gap by employing an external risk transfer mechanism, thereby enhancing the stability of cross-departmental cooperation. For example, when food processing companies enter into long-term "order agriculture" agreements with farmers, agricultural insurance generally covers the production and quality risk. This encourages food processing companies to invest in dedicated assets for the farmers, thereby enhancing the resilience of their contractual relationship. The case of Agricultural Development and Marketing (ADM) company and Monsanto company illustrates this well. ADM reduces supply risks for corn and soybeans by employing agricultural insurance, which allows them to expand their operations downstream into biofuel and food additive production. They utilize the profits from these industrial enterprises to subsidize agricultural research and development, creating a robust contractual framework known as "insurance protects production and industry protects profit". Monsanto also achieves vertical integration in agricultural planting, biotechnology research, and financial instruments, by bundling seed sales with the "seed + agricultural catastrophe index insurance" package.

Thirdly, industrial integration can contribute to the enhancement of agricultural resilience. The theory of industry convergence suggests that vertical integration not only enhances efficiency through internalized transactions but also achieves the goal of "nourishing agriculture with industry and empowering agriculture with services" via cross-departmental risk diversification, technological coordination, and supply chain reconstruction. This, in turn, strengthens the agricultural system's capacity to withstand risks and adapt to changes. Moreover, vertical integration would also lead to the creation of new business models and expands market space and growth opportunities, determining the agricultural system's transformability in coping with disruptions.

Based on the above analysis, the theoretical analysis framework diagram of agricultural insurance affecting agricultural resilience is shown in Figure 1.

4 Method and data

4.1 Empirical strategy

Firstly, to test the impact of agricultural insurance on agricultural resilience, we construct the following regression model.

$$Resilience_{it} = \alpha_1 + \beta_1 Insurance_{it} + \theta_1 Controls_{it} + \mu_i + \pi_t + \varepsilon_{it} \quad (1)$$

where $Resilience_{it}$ denotes the level of agricultural resilience of province i in year t; $Insurance_{i,t}$ denotes the development level of agricultural insurance; $Controls_{it}$ denotes the control variables; μ_i and π_t denotes provincial fixed-effect and year fixed-effect, which is used to control the impact of unobserved factors at the provincial and year levels, respectively; ε_{it} is a random error term.

Secondly, to examine the underlying mechanisms of how agricultural insurance affects agricultural resilience, we establish the following model based on formula (1).

$$Mediators_{it} = \alpha_2 + \beta_2 Insurance_{it} + \theta_2 Controls_{it} + \mu_i + \pi_t + \varepsilon_{it} \quad (2)$$

$$Resilience_{it} = \alpha_3 + \beta_3 Insurance_{it} + \beta_4 Mediators_{it} + \theta_3 Controls_{it} + \mu_i + \pi_t + \varepsilon_{it} \quad (3)$$

where $Mediators_{it}$denotes mediating variables, including agricultural agglomeration and industrial integration, respectively. According to the stepwise regression method (Wen et al., 2004), if $\beta_1, \beta_2, \beta_3$ and β_4 both are significant, it means that the mediation effect exists and the mediator variable plays a partially mediating role in the relationship between agricultural insurance and agricultural resilience; if $\beta_1, \beta_2, \beta_4$ are significant but β_3 is not significant, it means that the mediator variable plays a fully mediating role.

Thirdly, given the limitations of traditional stepwise regression approach, we also employ the Bootstrap method proposed by Preacher and Hayes (2004), and in accordance with Zhao et al. (2010) to examine the impact mechanisms.

4.2 Variable descriptions

4.2.1 Dependent variable

4.2.1.1 Agricultural resilience (*Resilience$_{it}$*)

The previous literature review indicates that evolutionary resilience reflects the dynamic changes of the system, which aligns with the adaptability and self-learning characteristics of the agricultural system when facing multiple complex risks. Adhering

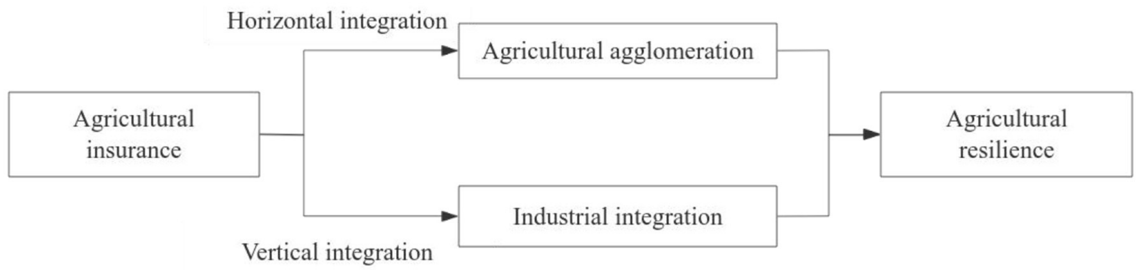

FIGURE 1
Framework for agricultural insurance affecting agricultural resilience.

to the concept of evolutionary resilience, this article constructs a comprehensive index to measure the level of agricultural resilience across three dimensions: risk resistance capacity, adaptation and adjustment capacity, and innovation and transformation capacity. The specific indicators presented in Table 1 mainly refer to the works of Hao and Tan (2022), Zhao and Xu (2023), Zhou et al. (2023), as well as Tang and Chen (2023), covering the agricultural production subsystem, agricultural ecological subsystem, and agricultural economic subsystem. Finally, the entropy weight method is utilized to assign weights to each indicator (see Table 1), thereby obtaining a comprehensive agricultural resilience index.

Risk resistance capacity signifies the capacity of the agricultural system to withstand disturbances when confronted with sudden destructive events. In this category, seven specific characterization indicators are selected. The proportion of agricultural added value in the regional GDP and the per capita disposable income of rural residents, as the key metrics for measuring the level of agricultural economic development, can reflect the risk-resistance capabilities of agricultural industries and agricultural business entities. Indicators such as agricultural acreage, effective irrigated area, and the total volume of water resources available for irrigation reveal the resource endowment of the agricultural system. Meanwhile, the yield per unit area of grain and the total power of agricultural machinery demonstrate the productivity of the agricultural system. Collectively, these strong agricultural production conditions and capacity can reflect the resilience of the agricultural production subsystem against external fluctuations.

Adaptation and adjustment capacity indicates the capacity of the agriculture system to revert to its original state following exposure to natural and market risks. This category also encompasses seven specific indicators. The growth rate of agricultural added value illustrates the vitality of agricultural industries, whereas the agricultural product producer price index indicates the fluctuation of agricultural input costs. Together, these two indicators reflect the adaptability of the agricultural economic subsystem to shocks from the positive and negative perspectives, respectively. Indicators such as the amount of fertilizer and pesticide applied, the use of agricultural plastic film, the area affected by disasters, and the extent of soil erosion control measures characterize the pressure on the agricultural ecological subsystem under the shock. This, in turn, determines the agricultural production subsystem's ability to recover to its original state.

Innovation and transformation capacity signifies the self-change and transformability of the agriculture system in response to shocks. This category includes three specific indicators: the fiscal expenditure on science and technology, the growth rate of fixed-asset investment, and the proportion of the rural illiterate population. These indicators reflect the RandD investment, material capital, and human capital required for the innovation and transformation of the agricultural system post-shock, determining the system's capacity to continue achieving sustainable development along a new growth trajectory.

4.2.2 Independent variable

4.2.2.1 Agricultural insurance ($Insurance_{it}$)

We select the natural logarithm of premium income as an indicator to gauge the development level of agricultural insurance. Additionally, for the robustness test, we utilize the natural logarithm of compensation expenditure as an alternative measure to assess the development level of agricultural insurance. In this article, the premium income is defined as the consideration income that the insurance company receives from the policyholder to fulfill the obligations stipulated in the insurance contract (such as agricultural enterprises, cooperatives, specialized farms, and farmers); the compensation expenditure is defined as the compensation amount of the original insurance contract and the reinsurance contract that the insurance company pays to the policyholder. Although the factors determining premium income and compensation expenditure are various and complex, these two indicators indirectly reflect the market share and business level of insurance companies from two different aspects: income and expenditure, respectively.

4.2.3 Mediating variables

(1) Agricultural agglomeration ($Agglomeration_{it}$). Referring to Tian and Yin (2021), this article measures the degree of agricultural agglomeration based on location entropy, and the specific formula is as follows.

$$Agglomeration_{it} = \frac{\frac{A_{it}}{\sum_{i=1}^{30} A_{it}}}{\frac{G_{it}}{\sum_{i=1}^{30} G_{it}}} \quad (4)$$

where A_{it} denotes the total output value of agriculture of province i; $\sum_{i=1}^{30} A_{it}$ denotes the national total output value of

TABLE 1 Indicators for agricultural resilience.

Primary indicator	Secondary indicator	Direction	Weight
Risk resistance capacity	Proportion of agricultural added value in the regional GDP(%)	Positive	0.035
	Per capita disposable income of rural residents (RMB 10 thousand yuan)	Positive	0.044
	Agricultural acreage (1,000 hectares)	Positive	0.072
	Effective irrigated area (1,000 hectares)	Positive	0.076
	Total volume of water resources available for irrigation (100 million cubic meters)	Positive	0.098
	Total power of agricultural machinery (million kilowatts)	Positive	0.079
	Per unit area yield of grain (tons)	Positive	0.019
Adaptation and adjustment capacity	Growth rate of agricultural added value (%)	Positive	0.054
	Agricultural product producer price index (Last year = 100)	Negative	0.016
	Amount of fertilizer application (tons)	Negative	0.069
	Amount of pesticide application (tons)	Negative	0.075
	Amount of agricultural plastic film used (tons)	Negative	0.144
	Disaster-affected area/thousand hectares (1,000 hectares)	Negative	0.006
	Area of soil erosion control (1,000 hectares)	Positive	0.071
Innovation and transformation capacity	Fiscal expenditure on science and technology (RMB 100 million yuan)	Positive	0.128
	Growth rate of fixed-asset investment (%)	Positive	0.013
	Proportion of the rural illiterate population (%)	Negative	0.002

agriculture; G_{it} denotes the total output value of all industries of province i; $\sum_{i=1}^{30} G_{it}$ denotes the national total output value of all industries.

(2) Industrial integration ($Integration_{it}$). Based on the availability of data, we select four indicators to represent the integrated development of agriculture with both the secondary and tertiary industries, as illustrated in Table 2. Subsequently, the entropy-weighted method is employed to construct a comprehensive index for assessing the integration level among primary, secondary, and tertiary industries.

4.2.4 Control variables

Since many variables related to agricultural development have been used in measuring agricultural resilience and industrial integration, we mainly consider the following control variables.

(1) Agricultural labor ($LnLabor_{it}$), measured by the natural logarithm of the number of agricultural workers.
(2) Rural human capital ($Human_{it}$), measured by per capita education level of rural residents.
(3) The level of regional economic development ($LnGDP_{it}$), measured by the natural logarithm of GDP per capita.
(4) Industrialization level ($Industrial_{it}$), measured by the ratio of the added value of the secondary industry to the total output value.
(5) Regional openness ($Open_{it}$), measured by the ratio of the total import and export of regional trade to GDP.
(6) Financial support for agriculture ($LnFinance_{it}$), measured by the natural logarithm of financial expenditure for agriculture.
(7) Environmental regulation intensity ($Regulation_{it}$), measured by the proportion of environmental pollution control investment in GDP.

4.3 Data

This article uses panel data from 2010 to 2022 at the provincial level in China. All the raw data comes from the website of the National Bureau of Statistics (NBS) and the China Statistical Yearbook, the China Rural Statistical Yearbook, and the statistical yearbooks of each province. The descriptive statistics of each variable are shown in Table 3.

5 Results and discussion

5.1 Baseline regression results

Based on the results of the Hausman test, it is deemed more appropriate to employ a fixed-effects model rather than a random-effects model for our analysis. Consequently, we have primarily utilized the fixed-effects model in our empirical examination. Table 4 presents the foundational regression results. Model 1 accounts solely for provincial fixed-effects, while model 2 incorporates both provincial and annual fixed-effects, and model 3 takes into account an additional series of control variables. The results from three models consistently indicate a significant and positive correlation between the advancement of agricultural insurance and agricultural resilience. This suggests that as the level of agricultural insurance increases, so does the resilience of agriculture.

TABLE 2 Indicators for industrial integration.

Primary indicator	Secondary indicator
Integrated development of agriculture and the secondary industry	The proportion of the income of the agricultural product processing industry in the total agricultural output value
	The proportion of the facility agricultural operating area in the total cultivated land area
Integrated development of agriculture with the tertiary industry	The proportion of the income of the leisure agriculture in the total agricultural output value
	The proportion of the total output value of agricultural service industry in the total agricultural output value

TABLE 3 Descriptive statistics of variables.

Variable	Observations	Std. Dev.	Mean	Min	Max
Resilience	390	0.252	0.104	0.067	0.505
Insurance_income	390	6.911	1.156	2.322	9.012
Insurance_expenditure	390	6.471	1.208	2.593	8.831
Agglomeration	390	6.311	1.107	3.045	7.905
Integration	390	7.776	0.611	5.848	9.915
LnLabor	390	5.873	3.048	1.312	19.031
Human	390	0.338	0.082	0.100	0.574
LnGDP	390	0.276	0.291	0.008	1.464
Industrial	390	6.152	0.609	4.222	7.215
Open	390	0.008	0.005	0.002	0.043
LnFinance	390	0.252	0.104	0.067	0.505
Regulation	390	0.151	0.087	0.037	0.633

5.2 Endogeneity consideration

In this study, endogeneity may stem from two sources. Firstly, it could be due to the exclusion of significant variables. Despite the inclusion of a comprehensive range of control variables, there may still be important factors influencing agricultural resilience and related to agricultural insurance that have not been accounted for. For instance, individual risk awareness and the vulnerability of local ecosystems not only influence farmers' decisions regarding agricultural production but also their purchasing decisions on agricultural insurance. However, these variables are often challenging to observe directly, and in the current scenario, we have not identified objective proxy variables to measure them. Secondly, there might exist a reverse causality between agricultural resilience and agricultural insurance. This is because insurance providers might be inclined to offer more insurance products in regions where agricultural resilience is stronger, thereby aiming to lower their payout ratios. To tackle these potential endogeneity concerns, we propose employing two sets of instrumental variables (IV).

The first IV set pertains to the quantity of landlines present in rural areas during the year 1984. This selection is primarily based on two considerations. Firstly, since insurance sales representatives and farmers often rely on telephone communication to conduct their business, the extent to which insurance penetrates rural communities is closely linked to advancements in communication technology. Before the advent of mobile phones, rural areas in China had relied mainly on landline phones for communication. Although mobile phones have gradually replaced landline phones, areas with historically higher landline penetration are also most likely to have higher mobile phone penetration, as they possess better communications infrastructure. This creates a correlation between the instrumental variable and the endogenous explanatory variable. Secondly, with the sharp decline in landline telephone usage, its impact on agricultural production also becomes very weak, meeting the exclusivity requirements of IV.

The second IV set pertains to the slope of the terrain. Firstly, the more pronounced the terrain's relief, the poorer the transportation infrastructure, resulting in increased time and transportation costs for conducting insurance operations in rural areas. Intuitively, there is an inherent correlation between the slope of the terrain and the extension of agricultural insurance in the area. Secondly, terrain relief, being an exogenous geographical factor, has a significantly diminished impact on agricultural production, thus fulfilling the criteria for an instrumental variable.

However, the historical quantity of landlines and the terrain slope are both classified as Section IV, which fail to capture the temporal evolution of agricultural insurance trends. Drawing on the work of Nunn and Qian (2014), as well as Zhao et al. (2020), we employ the interaction term between the number of landlines in 1984 and the previous year's rural Internet penetration rate,

TABLE 4 Baseline regression results.

Variables	Model 1	Model 2	Model 3
Insurance	0.054***	0.075***	0.033***
	(0.004)	(0.005)	(0.003)
LnLabor			0.082***
			(0.003)
Human			0.001
			(0.004)
LnGDP			0.014***
			(0.001)
Industrial			0.100***
			(0.034)
Open			0.077***
			(0.012)
LnFinance			−0.003
			(0.004)
Regulation			0.839*
			(0.493)
_cons	−0.126***	−0.269***	−0.627***
	(0.025)	(0.032)	(0.053)
Provincial fixed-effects	Yes	Yes	Yes
Year fixed-effects	No	Yes	Yes
Sample size	390	390	390
R^2	0.371	0.371	0.828

Standard error in parentheses; *, *** denote significant at 10% and 1% levels, respectively.

along with the interaction term between the reciprocal of terrain slope and the year trend, to construct our panel IV. As shown in Table 5, the Kleibergen-Paap rk Wald F statistics for the two sets of instrumental variables are 27.391 and 16.605, respectively. Both figures exceed the critical value of 16.38 recommended by Stock and Yogo (2005) for a 10% maximal IV size, thereby allowing us to reject the null hypothesis of "weak instrumental variables." Additionally, the Hansen J statistics yield *p*-values of 0.000, indicating no concerns regarding the over-identification of instrumental variables. Consequently, the two sets of instrumental variables selected in this study satisfy the necessary criteria.

The first stage results of 2SLS estimates presented in Table 5 show that both IV_1 and IV_2 are positively correlated with agricultural insurance at a 1% significance level. The results of the second stage reveal that agricultural insurance is also positively correlated with agricultural resilience at a 1% significance level. This suggests that even after addressing potential endogeneity issues, agricultural insurance continues to exert a significant impact on agricultural resilience. It should be noted that the aforementioned IV estimated coefficients represent only the average treatment effect for compliers, namely the local average treatment effect (LATE), and not the overall average treatment effect.

5.3 Robustness check

(1) Redefining agricultural insurance. To circumvent estimation bias resulting from measurement inaccuracies in agricultural insurance, we assess the advancement of agricultural insurance by substituting premium income with compensation expenditure. The results of model 8, as presented in Table 6, clearly indicate a significant impact of agricultural insurance on agricultural resilience.

(2) Replacing the fixed-effects with a random-effects. In model 9 of Table 6, we substitute the fixed-effects model with a random-effects model and continue to note a positive correlation between agricultural insurance and agricultural resilience.

5.4 Heterogeneity analysis

Given China's extensive territory, there exist considerable disparities in industrial and economic foundations, climatic conditions, and geographical features across various regions. It is thus pertinent to investigate whether these variations result in differing roles of agricultural insurance in bolstering agricultural resilience across these areas. Consequently, we undertake a heterogeneity analysis from the following two perspectives.

On the one hand, in accordance with administrative division, the samples are categorized into three distinct regions: Eastern, Central, and Western. The Eastern region encompasses 11 provinces, namely Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan. The Central region comprises 8 provinces, including Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan. The Western region consists of 11 provinces, specifically Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang.

On the other hand, based on the relationship between grain yield and grain sales, the samples are further divided into three distinct groups: the main grain-producing regions, the main grain-selling regions, and the production and marketing balance regions. The major grain-producing regions cover 13 provinces including Hebei, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Jiangsu, Anhui, Jiangxi, Shandong, Henan, Hubei, Hunan and Sichuan; the main grain-selling regions cover seven provinces including Beijing, Tianjin, Shanghai, Zhejiang, Fujian, Guangdong and Hainan; and the production and marketing balance regions cover 10 provinces including Shanxi, Shaanxi, Gansu, Qinghai, Ningxia, Yunnan, Guizhou, Chongqing, Guangxi and Xinjiang.

The results of model 10, as illustrated in Table 7, indicate that the influence of agricultural insurance on agricultural resilience does not significantly vary between the Eastern and Central regions. However, the impact on agricultural resilience in the Western region is notably lower than that observed in both the Eastern and Central regions. As illustrated in model 11, the impact of agricultural insurance on the resilience of agricultural systems, ranging from strong to weak, is observed in the main grain-producing regions, the main grain-selling

TABLE 5 Robustness test results.

Variables	Model 4	Model 5	Model 6	Model 7
	IV_1 = number of landlines in 1984		IV_2 = reciprocal of terrain slope	
	First stage	Second stage	First stage	Second stage
IV_1	0.203***			
	(0.039)			
IV_2			0.013***	
			(0.003)	
Insurance		0.057***		0.050***
		(0.011)		(0.014)
Controls	Yes	Yes	Yes	Yes
Kleibergen-Paap F statistic	27.391		16.605	
Hansen J statistic	$P = 0.000$		$P = 0.000$	
Sample size	390	390	390	390
R^2	0.500	0.781	0.448	0.804

Standard error in parentheses; *** denotes significant at 1% level.

TABLE 6 Robustness test results.

Variables	Model 8	Model 9
Insurance_expenditure	0.032***	
	(0.003)	
Insurance_income		0.033***
		(0.003)
Controls	Yes	Yes
Sample size	390	390
R^2	0.836	0.829

Standard error in parentheses; *** denotes significant at 1% level.

regions, and the regions where production and marketing are balanced.

5.5 Mechanism test

On the one hand, we employ a stepwise regression approach to scrutinize the mechanisms. Step 1 involves assessing the overall impact of agricultural insurance on agricultural resilience, as demonstrated in Table 4. Step 2 entails examining the influence of agricultural insurance on agricultural agglomeration and industrial integration, respectively. Step 3 focuses on evaluating the mediating effects of the mediators on agricultural resilience, alongside the direct impact of agricultural insurance on the same. From the results presented in Table 8, we can distill several key insights. Firstly, in comparison with the baseline regression results of model 3, the estimation coefficients for agricultural insurance on agricultural resilience are significantly reduced in model 13 and model 15 after incorporating mediation variables. This indicates that the channel through which agricultural insurance affects agricultural resilience via intermediary variables is established. Secondly, concerning the mediating effect of agricultural agglomeration, the results from model 12 and model 13 suggest that agricultural insurance significantly enhances agricultural agglomeration, while agricultural agglomeration in turn significantly fosters agricultural resilience. This suggests that agricultural insurance not only directly enhances agricultural resilience but also indirectly fosters it by boosting the level of industrial agglomeration within the agricultural sector. Thirdly, regarding the mediating role of industrial integration, the outcomes of model 14 and model 15 indicate that industrial integration

TABLE 7 Results of heterogeneity regression based on administrative divisions.

Variables	Model 10	Model 11
	Compare with Eastern	Compare with grain producing area
Insurance	0.037***	0.030***
	(0.003)	(0.003)
Insurance×Central	−0.001	
	(0.001)	
Insurance×Western	−0.007***	
	(0.001)	
Insurance×Selling		−0.003***
		(0.001)
Insurance×Balance		−0.008***
		(0.001)
Controls	Yes	Yes
Sample size	390	390
R^2	0.854	0.857

Standard error in parentheses; *** denotes significant at 1% level.

significantly enhances agricultural resilience, but agricultural insurance appears to diminish the level of industrial integration. In essence, while industrial integration has the potential to strengthen agricultural resilience, agricultural insurance might impede the convergence of the agricultural sector with the industrial and service sectors, thereby creating a masking effect that obstructs the improvement of agricultural resilience. Fourthly, both mediation variables are included simultaneously in model 16 to compare the magnitude of the mediation effects of agricultural agglomeration and industrial integration. For this we can calculate the mediation effect ($\beta_2^*\beta_4$) of agricultural agglomeration and industrial integration is 0.003 and −0.002, respectively. It is evident that the positive mediating role of the agricultural agglomeration mechanism outweighs the negative mediating role of the industrial integration mechanism, ensuring that the combined indirect effect of agricultural insurance on agricultural resilience remains positive.

On the other hand, considering the limitations of the stepwise regression approach, we additionally employ the Bootstrap method to examine the impact mechanisms. In the stepwise regression method, for example, we identified the mediation effect (i.e., the indirect effect of the independent variable on the dependent variable through the mediating variable) by calculating the product of the estimated coefficient of the independent variable on the mediating variable (β_2) and the estimated coefficient of the mediating variable on the dependent variable (β_4). However, the nature of the product of β_2 and β_4 introduces two challenges to the significance test of the mediation effect. Firstly, the distribution of the indirect effect is often non-normal, particularly when the sample size is small or the effect is weak, rendering traditional significance tests (such as the *t*-test) susceptible to estimation bias. Secondly, the standard error of the indirect effect is challenging to estimate directly, which further complicates the significance test. The Bootstrap method, as a non-parametric statistical approach, does not depend on any distributional assumptions. Instead, it estimates the distribution of indirect effect through repeated sampling from the original sample and assesses significance using confidence intervals. Furthermore, the standard error of indirect effect can be estimated through extensive repeated sampling. The Bootstrap-test results displayed in Table 9 suggest that agricultural insurance primarily bolsters agricultural resilience through the encouragement of agricultural agglomeration, rather than through the promotion of industrial integration.

5.6 Discussion on the main findings

The above results demonstrate three main findings. Firstly, our results confirm the previous studies (Ling and Zhao, 2024; Zhou et al., 2023), indicating that agricultural insurance significantly contributes to the enhancement of agricultural resilience. This largely stems from the multifaceted functions that agricultural insurance offers, which include risk prevention, in-process risk compensation, and comprehensive post-risk management. These functions collectively work to fortify the agricultural sector against various uncertainties and adversities, thereby bolstering its overall resilience and adaptability.

Secondly, agricultural insurance can enhance agricultural resilience by promoting industrial agglomeration within the agricultural sector. This is largely due to the expanded functions of agricultural insurance. For instance, it encourages the return of skilled labor to the agricultural sector, leading to the concentration of human capital; promotes the adoption and diffusion of advanced agricultural technology, resulting in spillover effects of technology and knowledge; and triggers the sinking of productive services such as finance, information, and logistics to support agricultural industrialization. These factors are crucial for the formation of agricultural agglomeration. Nonetheless, the relationship between market structure and corporate growth performance has been a topic of long-standing discussion (Acs and Audretsch, 1987; Drucker and Feser, 2012). The "size scepticism" said that a concentrated industrial structure could exacerbate the risk infection among enterprises (Zhai, 2013). In our view, this underscores the importance of the risk dispersion function of insurance in mitigating the adverse effects of industrial agglomeration. Additionally, we also emphasize the significance of the government's industrial planning. In fostering the concentrated development of agricultural industries, the Chinese government has established the primary direction of characteristic industries, aligning with local resource endowment, industrial base, and regional advantages. Resulting in an agricultural industrialization development pattern characterized by "one village, one product" and "one town, one industry". This kind of top-level industrial planning can effectively prevent the consequences of excessive homogenization that often arise from industrial agglomeration.

Thirdly, the mechanism through which agricultural insurance enhances agricultural resilience via industrial integration has not been verified. While our findings corroborate the previous research by Hao and Tan (2022), indicating that industrial integration can bolster agricultural resilience. We also present evidence suggesting that, at this stage, agricultural resilience impedes industrial integration, which contradicts the theoretical hypothesis. We suggest that this is mainly due to the limited variety of China's agricultural insurance products and the significantly inadequate coverage rate. In China, there are over 5,000 major varieties of crops, yet only 16 are covered by agricultural insurance, indicating a significant disparity between the number of agricultural insurance products available and those found in developed nations such as the United States, Canada, and Japan. Moreover, the current agricultural insurance products primarily cover the three main grains—rice, corn, and wheat—and seldom include livestock breeding and cash crops. Notably, agricultural products with local characteristics are typically excluded from the scope of agricultural insurance. Agricultural insurance, by dispersing the risk associated with major food crops, actually encourages increased investment of capital, technology, and labor into grain-related industries. However, numerous successful practices demonstrate that extending the agricultural industry chain around featured agricultural products is the primary model for the integrated development of primary, secondary, and tertiary industries. Besides, from the perspective of the supply chain, the current insurance products primarily cover agricultural production links and lack compound insurance products that encompass "agricultural production, industrial processing, and market circulation", which further limits the

TABLE 8 Mechanism analysis based on a stepwise regression approach.

Variables	Model 12	Model 13	Model 14	Model 15	Model 16
	Agglomeration	Resilience	Integration	Resilience	Resilience
Insurance	0.164***	0.020***	−0.021***	0.021***	0.018***
	(0.027)	(0.003)	(0.005)	(0.003)	(0.005)
Agglomeration		0.022***			0.018***
		(0.005)			(0.003)
Integration				0.130***	0.110***
				(0.030)	(0.031)
Controls					
Sample size	390	390	390	390	390
R^2	0.717	0.884	0.623	0.883	0.884

Standard error in parentheses; *** denotes significant at 1% level.

TABLE 9 Mechanism analysis based on Bootstrap approach.

Variables	Model 17	Model 18
	Agricultural agglomeration mechanism	Industrial integration mechanism
Direct effect	0.028***	0.031***
	(0.003)	(0.003)
Indirect effect	0.003***	−0.0002
	(0.001)	(0.0003)
Controls	Yes	Yes
Sample size	390	390

Standard error in parentheses; *** denotes significant at 1% level.

potential of agricultural insurance as a link to promote the integration of primary, secondary and tertiary industries.

6 Conclusions and policy implications

A resilient agricultural system can avoid, mitigate or recover from adverse impacts while maintaining or enhancing its productivity, sustainability and social welfare. This study pioneers the exploration of the role of agricultural insurance in bolstering Chinese agricultural resilience. To achieve this, a comprehensive index was developed to assess the agricultural resilience. Subsequently, by analyzing provincial-level data from China between 2010 and 2022, the study examined the impact and underlying mechanisms of agricultural insurance on agricultural resilience, considering the perspectives of agricultural agglomeration and industrial integration.

The main conclusions are as follows. (1) The advancement of agricultural insurance has played a significant and positive impact on bolstering agricultural resilience. These conclusions remain valid even after accounting for endogenous factors through the application of two IV sets. (2) Regarding the underlying mechanisms, agricultural insurance primarily enhances agricultural resilience by encouraging agricultural agglomeration, rather than by fostering industrial integration. (3) The influence of agricultural insurance on agricultural resilience differs among regions. Specifically, its impact on the agricultural resilience in the eastern and central regions is significantly stronger than that in the western regions. Furthermore, agricultural insurance has a considerably more significant effect on agricultural resilience in the major grain-producing regions compared to its influence in the main grain-selling areas. Additionally, the effect of agricultural insurance on agricultural resilience in the main grain-selling areas is notably more substantial than in regions with a balanced production and marketing profile.

The findings offer several implications for policymakers, financial institutions, and other stakeholders. Firstly, policymakers should seek to utilize agricultural insurance to enhance the resilience of agricultural system, including education on insurance related knowledge for policyholders to promote their purchasing motivations. Secondly, strengthening agricultural agglomeration should be an integral component of the toolkit that governments employ to stimulate the positive role of agricultural insurance in enhancing agricultural resilience. Thirdly, our findings indicate that industrial integration can enhance agricultural resilience. However, at this stage, agricultural insurance significantly hinders industrial integration. Therefore, insurance companies should focus on strengthening the design and innovation of insurance products to better serve industrial integration. Fourthly, insurance companies should also pay more attention to expanding the coverage of agricultural insurance in areas with underdeveloped agricultural systems.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

CX: Conceptualization, Formal analysis, Investigation, Writing – original draft. Y-pK: Writing – review & editing. H-xW: Data curation, Funding acquisition, Methodology, Software, Writing –

review & editing. X-qW: Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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