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RECEIVED 25 November 2025

REVISED 10 February 2026

ACCEPTED 10 February 2026

PUBLISHED 12 March 2026

##### CITATION

Zhang R, Zhou K, Fang F, Chen Y,  
Zhang G and Yang C (2026) Impact of  
farmer cooperatives' transaction model  
on members' chemical pesticide  
reduction behaviour: evidence from  
rural China.

*Front. Sustain. Food Syst.* 10:1754118.

doi: 10.3389/fsufs.2026.1754118

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# Impact of farmer cooperatives' transaction model on members' chemical pesticide reduction behaviour: evidence from rural China

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Amidst the rapid expansion of farmer cooperatives in China, effectively leveraging these organisations to encourage members to reduce chemical pesticide use holds significant implications for ensuring food safety and advancing high-quality agricultural development. Existing research has predominantly focused on whether farmers joining farmer cooperatives influence their green production behaviour, while generally overlooking the pronounced heterogeneity among farmer cooperative members in China. Ordinary members' choice of the farmer cooperatives' transaction model essentially constitutes a proactive embedding within different institutional arrangements. The series of contractual designs, oversight mechanisms, and incentive structures underpinning the farmer cooperatives' transaction model influences members' green production practices. Therefore, based on survey data from 608 farmer cooperative members in Sichuan Province, this paper employs an endogenous switching regression model to construct a counterfactual framework. Addressing endogeneity issues reveals that members' selection of the farmer cooperatives' transaction model favours improved chemical pesticide reduction behaviour. The transmission mechanism shows that the improvement in members' chemical pesticide reduction behaviour, driven by the farmer cooperatives' transaction model, stems from, in order of contribution, surplus distribution incentives, product delivery standards, production factor input constraints, and production service incentives. Heterogeneity analysis further indicates that the transaction model of farmer cooperatives with companies, fruit merchants, and e-commerce platforms enhances members' chemical pesticide reduction behaviour by 57.6%, 43.4%, and 44.3%, respectively. To strengthen the role of farmer cooperatives in promoting agricultural green transformation and chemical pesticide reduction, this paper proposes four policy recommendations. First, refine internal governance within farmer cooperatives to strengthen institutional designs that balance incentives and constraints. Second, expand stable partnerships between farmer cooperatives and companies to establish robust order systems and deep cooperation models centred on 'premium prices for premium quality'. Third, enhance technical training and unified agricultural input services to reduce transition costs for members. Fourth, leverage demonstration effects within villages to create a collective atmosphere for green production, using 'group effects' to drive a holistic transformation among members.

## KEYWORDS

chemical pesticide reduction behaviour, cooperatives, endogenous switching regression model, rural China, transaction mode

## 1 Introduction

To control pests and diseases while boosting crop yields, chemical pesticides have become ubiquitous in agricultural production (Sharma et al., 2020), serving as a critical input in global modern agriculture (Bagheri et al., 2018). In 2023, China's total chemical pesticide use remained high at 229,000 tonnes, ranking among the world's top five, exerting persistent pressure on the agricultural environment. The long-term excessive and irrational application of chemical pesticides in Chinese agricultural production has exacerbated issues such as declining soil quality in cultivated land and agricultural non-point source pollution, posing serious threats to ecosystems, human health, and food safety (Sun et al., 2023). China's smallholder farmers number approximately 203 million, constituting 98.1% of all agricultural operators and managing 70% of the total cultivated land area. They represent the pivotal actors in advancing green agricultural development (Ministry of Agriculture and Rural Affairs of the People's Republic of China, 2024). Consumer markets manage farmers' production behaviour through game-theoretic rules, exhibiting characteristics of lag and repetition; government regulation of individual farmers incurs high costs and suffers from indirectness and untimeliness (Gong et al., 2023). This necessitates the introduction of alternative intermediary mechanisms to facilitate shifts in smallholder production and management behaviour (Cheng and Zheng, 2018). Against this backdrop, farmers' farmer cooperatives—as a key institutional arrangement for organising smallholder farmers—are increasingly recognised for their potential to guide members toward green production methods. The Chinese government has vigorously supported farmer cooperatives; since the promulgation of the Farmers' Professional Farmer cooperatives Law of the People's Republic of China, farmer cooperatives have proliferated like mushrooms after rain. By the end of March 2024, the national total reached 2.197 million farmer cooperatives, with nearly 4 million family farms registered in the national family farm directory system. Additionally, 502,000 new agricultural business entities had registered trademarks or obtained agricultural product quality certifications.

Existing research indicates that farmers joining farmer cooperatives improves their allocation of production factors through multiple means, including implementing standardised production, providing socialised services, and obtaining product quality certification (Olagunju et al., 2021). Manda et al. (2020) argue that when smallholder farmers join farmer cooperatives, crop yields, household income, and household assets all see significant increases, while production input costs and market transaction costs decrease. Fink et al. (2024) contend that farmer cooperatives membership positively impacts farmers' access to diverse technologies, resource sharing, and market expansion, thereby boosting income and reducing transaction costs. Zhang et al. (2020) argue that within China's structurally constrained “large country, small-scale farming” context, agricultural farmer cooperatives can integrate modern production factors—such as improved crop varieties, contemporary technologies, mechanised equipment, and modern organisational models—into smallholder farming behaviour, thereby bridging the gap between fragmented

smallholder agriculture and modern agricultural development. Zhou et al. (2024) empirical research confirms that farmer cooperatives enhance smallholders' collective bargaining power through multiple mechanisms, empower them to mitigate market risks, and advance dual objectives of poverty reduction and food security. Ma et al. (2018) contend that farmer cooperatives' membership significantly and positively influences members' decisions to invest in organic soil conditioners and fertilisers. However, some studies indicate that joining farmer cooperatives does not necessarily promote green production behaviour among farmers. Candemir et al. (2021) contend that while farmer cooperatives may assist farmers in increasing yields, they could also incentivise the accelerated use of fertilisers and chemical pesticides for quicker returns, thereby damaging the environment. Concurrently, due to pronounced free-riding issues and member heterogeneity, farmer cooperatives do not invariably promote green production behaviour; they may even occasionally lead to diminished product quality or environmental performance. Lu et al. (2025) found that agricultural enterprises play a crucial role in encouraging smallholder farmers to reduce fertiliser usage and costs while improving fertiliser use efficiency. In contrast, farmer cooperatives' membership itself has no significant effect.

The aforementioned contradictions stem precisely from existing research's widespread neglect of the pronounced heterogeneity among Chinese farmer cooperatives members. Some farmer cooperatives maintain only loose transactional relationships with members, while others deeply embed themselves in members' production decisions through tight benefit-linkage mechanisms. Ignoring these vast differences in internal governance structures and conflating diverse farmer cooperative members leads to severe “selection bias” and “mean-level masking” in research conclusions. Concurrently, existing literature has identified significant variations in the nature of transactions between the farmer cooperatives and their members. These differences encompass the services provided by farmer cooperatives during members' agricultural production processes—such as inputs, information, and technical support (Li and Lu, 2020)—alongside the intensity of regulatory oversight. Furthermore, the social trust and reciprocal relationships formed during transactions exert heterogeneous influences on members' production behaviours (Cai, 2011).

Consequently, this paper employs the farmer cooperatives' transaction model as the core variable to illuminate the “black box” of internal governance. Rather than asking “Is joining a farmer cooperative beneficial?” we probe “Which institutional arrangements within transaction models prove most effective?” We further investigate which specific clauses within farmer cooperatives' transaction agreements drive members' chemical pesticide reduction behaviour, thereby explaining why some farmer cooperatives successfully guide green production while others remain largely ineffective. Building upon this analysis, we shall utilise data from 608 farmer cooperative members in Sichuan Province. Employing an endogenous switching regression (ESR) model, we investigate the impact of farmer cooperatives' transaction modes on members' chemical pesticide reduction behaviour. A parametric model will be applied to examine the underlying mechanisms. Furthermore, we explore how heterogeneous transaction modes between farmer cooperatives and external market

actors influence the extent of members' chemical pesticide reduction behaviours, thereby enriching the existing research literature.

## 2 Theoretical analysis and research hypotheses

Within China's agricultural structure, dominated by smallholder farming, the farmers' cooperatives serve as organisational vehicles bridging smallholders and large markets, possessing the potential to guide members toward green transformation. However, significant heterogeneity exists among cooperative members, alongside loose and inconsistent transaction patterns, and the institutional effectiveness of these cooperatives remains unsystematically analysed. This paper, therefore, examines the 'cooperative transaction model' as a micro-level institutional arrangement, exploring how specific institutional designs influence members' pesticide reduction practices. Upon joining the farmer cooperative, farmers may choose to transact agricultural produce through the farmer cooperative itself, or alternatively engage in trade with other market entities such as agribusinesses, supermarkets, wholesale markets, agricultural brokers, and consumers. Compared to external open-market trading models, the farmer cooperative trading model involves the cooperative (as organiser), its members (as producers), and external market participants. Through the dual mechanisms of internal regulations (such as input lists, quality standards, and surplus distribution) and external contracts (such as sales orders and certification requirements), cooperatives establish a multi-layered interactive relationship between the organisation, its members, and the market. This structure influences members' behaviour toward reducing pesticide usage.

Firstly, by enhancing bargaining power and establishing a 'premium for quality' mechanism, the farmer cooperatives alter the cost-benefit structure of members' production practices, creating sustained economic incentives. The farmer cooperatives negotiate on behalf of members with purchasing entities, thereby strengthening market leverage and shifting members from passive price-takers to active participants (Yuan, 2013). This recaptures a portion of profits previously captured by intermediaries (Xu et al., 2017; Serra and Davidson, 2021). More significantly, the farmer cooperatives enhance the market competitiveness of green agricultural products by obtaining stringent quality certifications (Zhang et al., 2024). The 'premium for quality' mechanism operates on an essentially economically rational basis, translating the transition to green production methods into

predictable, higher economic returns, thereby providing members with sustained behavioural incentives (Li and Lu, 2020). Secondly, the farmer cooperatives reduce institutional constraints and technical barriers to behavioural transformation by economising on transaction costs and providing supporting services. Through collective action, they lower transaction costs associated with transportation, information search, and negotiations (Cai, 2011; Zhou et al., 2019; Liu and Wu, 2022), while offering financial support for members to adopt green production technologies and optimise factor allocation. On the one hand, the farmer cooperatives impose binding constraints on members' pesticide application practices through unified input specifications and product quality standards, thereby reducing potential misuse at source. On the other hand, by providing production services such as technical guidance and information dissemination, the farmer cooperatives assist members in mastering pesticide-reduction substitution techniques and identifying market demands, effectively mitigating the cognitive risks and technical difficulties associated with behavioural transformation (Hendrikse and Veerman, 2008).

Consequently, this study proposes H1: The farmer cooperatives' transaction model exerts a significant positive influence on members' reduced chemical pesticide application behaviour.

As transaction frequency and volume between members and farmer cooperatives increase alongside enhanced transaction stability, more complex economic-social interactions emerge between them. Therefore, building upon existing research, this paper decomposes the mechanism through which the farmer cooperatives' transaction model influences members' reduced chemical pesticide application behaviour (Figure 1).

First, farmer cooperatives typically establish explicit institutional arrangements governing the types and brands of agricultural inputs selected by members who adopt the farmer cooperatives' transaction model (Zhong et al., 2016). These arrangements primarily take two forms: members either purchase agricultural inputs compliant with the farmer cooperatives' prescribed input list from relevant agricultural input dealers, or the farmer cooperatives centrally supply agricultural inputs such as chemical pesticides and fertilisers used in production (Zhao et al., 2014). When providing input lists, farmer cooperatives select reputable brands and higher-quality inputs, thereby limiting members' choices and preventing indiscriminate purchasing or misuse of agricultural inputs. Centralised supply reduces the likelihood of members acquiring counterfeit or inefficient inputs, helping to control input quality (Zhao and Zhang, 2009). Regarding

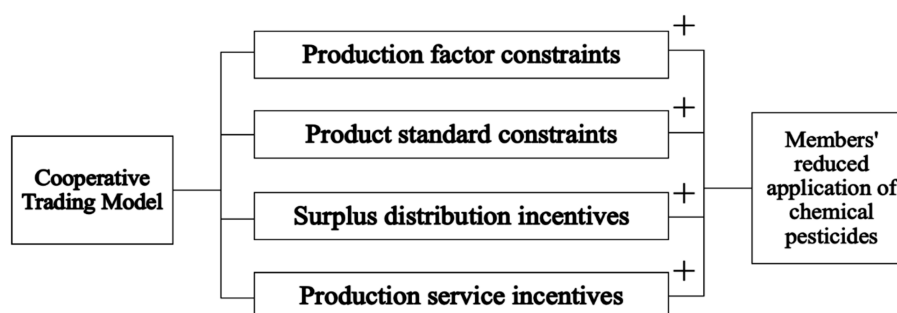


FIGURE 1

Mechanism diagram of farmer cooperatives' transaction model influencing members' chemical pesticide reduction behaviour.

input pricing, cooperatively supplied inputs are typically sold to members at cost price or wholesale rates (Liu et al., 2025), or the cost of inputs is deducted after the unified sale of produce, thereby enhancing farmers' liquidity.

Second, upon adopting the farmer cooperatives' transaction model, members and the farmer cooperatives reach a mutual agreement on product quantity, quality, and pricing terms. Existing research demonstrates that product quality certification represents an effective contemporary approach to controlling agricultural inputs at source (Kleemann and Abdulai, 2013). As a primary new type of agricultural business entity, farmers' farmer cooperatives serve as a crucial organisational vehicle for obtaining product quality certification (Kuan et al., 2021). By implementing stringent product quality certification, farmer cooperatives foster a new production and operational environment, imposing higher standards on members' agricultural product delivery quality (Papista and Krystallis, 2013). Concurrently, requiring product procurement to meet quality certification standards enables members to share in value-added gains along the agricultural product supply and value chains. The resulting premium incentives provide financial support for members to introduce optimised factor allocation (Blackman and Naranjo, 2012).

Third, the surplus distribution system constitutes a core component of farmer cooperatives' governance structures (Han et al., 2025) and functions as an incentive compatibility mechanism. Firstly, this system elevates the significance of product sales within profit allocation, thereby guiding and incentivising members to sell agricultural produce to the farmer cooperatives (Hosseini-Motlagh et al., 2022), fostering mutual benefit for both collective and individual interests. The greater the member's involvement in the farmer cooperatives, the larger their share of surplus distribution, effectively stimulating member enthusiasm and enhancing the farmer cooperatives' organisational cohesion (Awoke, 2021; Saz-Gil et al., 2021). Secondly, the surplus distribution system encourages the formation of a "risk-sharing, profit-sharing" linkage mechanism between members and the farmer cooperatives, significantly improving member compliance rates and agricultural product quality (Asrol et al., 2020; Han et al., 2025). Finally, the surplus distribution system also compels farmer cooperatives to innovate their operations and transform production methods to expand market access (Gu and Yu, 2022).

Fourth, farmers prioritise sales channel information and market price intelligence in agricultural production (Gao and Niu, 2019). Farmer cooperatives serve as the connecting link between smallholder farmers and large markets, conveying green agricultural product market demands and standards to members, thereby reducing their information collection and processing costs (Yu and Nilsson, 2021). Farmer cooperatives' information services effectively mitigate information asymmetry during members' green production processes, helping them overcome information barriers. This enables members to better understand the role of green production in increasing crop yields and income, improving the ecological environment, and protecting human health, thereby optimising their factor allocation (Kirezieva et al., 2016).

Consequently, this study identifies four key operational mechanisms—constraints on production inputs, constraints on product delivery standards, surplus distribution incentives, and production service incentives—which collectively form a dual-drive institutional toolkit of 'constraints and incentives'. This provides a testable theoretical framework for explaining how cooperative transaction models influence members' pesticide reduction practices.

Consequently, this study proposes H2: The production factor constraint mechanism within the farmer cooperatives' transaction model exerts a significant positive influence on members' chemical pesticide reduction behaviour.

H3: The product standard constraint mechanism of the farmer cooperatives' transaction model exerts a significant positive influence on members' chemical pesticide reduction behaviour.

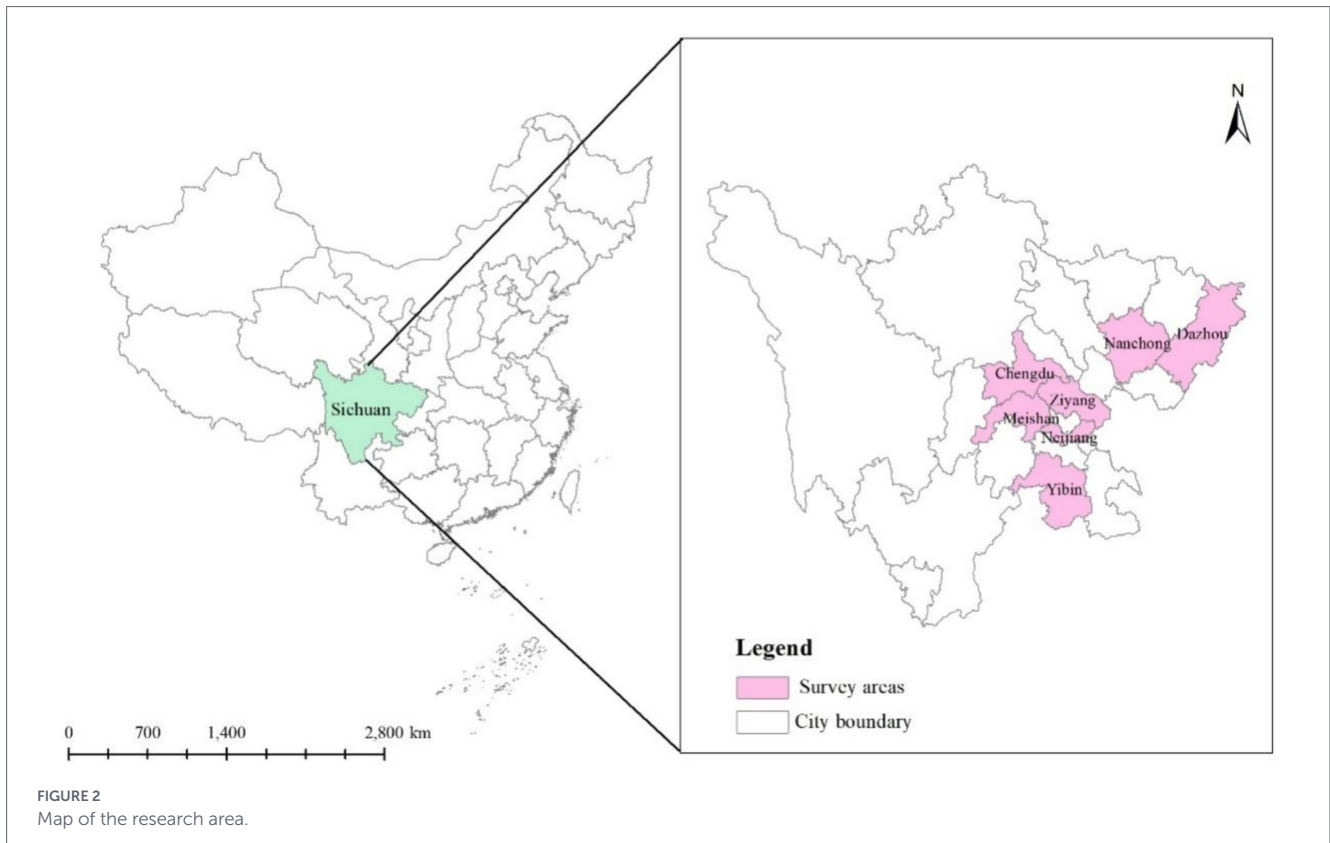
H4: The surplus distribution incentive mechanism of the farmer cooperatives' transaction model exerts a significant positive influence on members' chemical pesticide reduction behaviour.

H5: The production service incentive mechanism of the farmer cooperatives' transaction model exerts a significant positive influence on members' chemical pesticide reduction behaviour.

## 3 Data sources, model construction, and variable selection

### 3.1 Data sources

The data utilised in this paper originates from a questionnaire survey conducted by the research team between July and August 2021 among farmer cooperatives across nine major citrus-producing counties in Sichuan Province. The selection of survey areas was primarily guided by two considerations: firstly, Sichuan Province stands as one of China's foremost citrus-producing regions, where complex topography and diverse climatic conditions provide favourable circumstances for citrus cultivation, establishing it as the nation's largest base for late-ripening citrus varieties. Data indicates that by 2024, Sichuan's citrus cultivation area exceeded 8 million mu (approximately 533,333 hectares), with annual output surpassing 6 million tonnes, accounting for 15% of the national total. Late-season citrus alone covered 3.5 million mu (approximately 233,333 hectares), representing 60% of the national output for this category. This growth trajectory continues, maintaining a substantial share in China's citrus production. Secondly, compared to the development of grain, cotton, oilseed, and sugarcane – industries vital to national food security – in the plains, citrus cultivation holds significant importance for economic development in China's southern hilly and mountainous regions. It plays a crucial role in increasing farmers' incomes and alleviating poverty in these areas, employing substantial rural labour forces, and is integral to implementing the rural revitalisation strategy and consolidating poverty alleviation achievements. The survey employed a combined method of stratified multistage sampling and random sampling. The specific sampling process was as follows: First, based on citrus yield, cultivation area, and economic development, nine representative citrus-producing counties were selected in Sichuan Province: Jintang County, Renshou County, Danling County, Peng'an County, Gaoping District, Zizhong County, Qu County, Dachuan District, and Yanjiang District (Figure 2). Secondly, discussions were held with relevant officials in the sampled counties to understand the current state of the local citrus industry and farmer cooperatives' operations. Relevant units were requested to provide lists of typical citrus farmer cooperatives, from which the research team randomly selected 6–10 farmer cooperatives



for investigation. Within each farmer cooperative, 8–12 members were randomly selected for further research. A total of 638 questionnaires were distributed to farmer cooperatives. After excluding those with missing data or inconsistent information, 608 valid farmer cooperatives questionnaires were obtained, yielding a response rate of 95.29%. The questionnaire survey primarily employed one-to-one interviews with household heads or key family members involved in production decisions. Content covered respondents’ personal characteristics, household attributes, and agricultural production and management conditions.

### 3.2 Model construction

#### 3.2.1 The endogenous switching regression

Members decide whether to trade agricultural products through the farmer cooperatives based on their resource endowments. Their decision-making may be influenced by unobservable factors, which in turn affect chemical pesticide reduction behaviour. Previous studies often employed propensity score matching (PSM) to address selection bias, yet this method considers only observable variables influencing members’ choice of transaction patterns, overlooking endogeneity issues arising from unobservable factors. Therefore, this paper employs the endogenous switching regression (ESR) model proposed by Lokshin and Sajaia (2004) to analyse differences in chemical pesticide reduction behaviour between transaction and non-transaction members, thereby estimating the average treatment effect of farmer cooperatives’ transaction patterns on members’ chemical pesticide reduction behaviour. The endogenous switching regression model offers several advantages: (1) it resolves both the self-selection issue and endogeneity in members’ choice of farmer cooperatives’ transaction patterns, while

accounting for both observable and unobservable factors; (2) it enables separate estimation of chemical pesticides reduction behaviour equations for transactional and non-transactional group members, examining differentiated effects of various factors; (3) it employs full information maximum likelihood estimation to further address the issue of information omission; (4) Enables counterfactual analysis. Based on this, the following econometric model is constructed to evaluate the farmer cooperatives’ transaction model’s impact on members’ chemical pesticide reduction behaviour:

Choice behaviour equation (whether to opt for the farmer cooperatives’ transaction model):

$$A_i = \delta'Z_i + k'I_i + \mu_i \tag{1}$$

Outcome Equation 1 (Treatment group: Chemical pesticides reduction behaviour equation for members opting for the farmer cooperatives’ transaction model):

$$Y_{ia} = \beta'_a X_{ia} + \sigma_{ua} \lambda_{ia} + \varepsilon_{ia} \tag{1a}$$

Result Equation 2 (Treatment group, chemical pesticides reduction application behaviour equation for members not opting for the farmer cooperatives’ transaction model):

$$Y_{in} = \beta'_n X_{in} + \sigma_{un} \lambda_{in} + \varepsilon_{in} \tag{1b}$$

In Equation 1a,  $A_i$  denotes the binary choice variable indicating whether a member opts for the farmer cooperatives’ transaction

model;  $Z_i$  represents various factors influencing this choice;  $\varepsilon_i$  is the error term; and  $I_i$  is the identification variable. It should be noted that this study employs the proportion of members choosing the farmer cooperatives' transaction model at the village level as an instrumental variable, incorporating it into the model for member choice. In Equations 1a, 1b,  $Y_{ia}$  and  $Y_{in}$  denote the green production behaviour of the two sample groups comprising transaction and non-transaction members, respectively;  $X_{ia}$  and  $X_{in}$  represent a series of factors influencing members' chemical pesticide reduction behaviour;  $\varepsilon_{ia}$  and  $\varepsilon_{in}$  constitute the error terms of the outcome equations;  $\delta'$ ,  $k'$ ,  $\beta'_a$ ,  $\beta'_n$  are the estimated parameters obtained via the full information maximum likelihood method. Typically, the ESR model comprises two stages: the first stage employs maximum likelihood estimation for the behavioural equation (Probit or Logit model); The second stage incorporates the inverse Mills ratios  $\lambda_{ia}$  and  $\lambda_{in}$ , along with their covariances  $\sigma_{ua} = \text{cov}(\mu_i, \varepsilon_{ia})$  and  $\sigma_{un} = \text{cov}(\mu_i, \varepsilon_{in})$ , obtained from the first stage, into the outcome equation to estimate changes in chemical pesticides application behaviour resulting from members' choice of farmer cooperatives' transaction patterns.

The estimated results of the ESR model reveal the differential effects of various factors on chemical pesticide reduction behaviour between transaction and non-transaction members. To assess the overall impact of the farmer cooperatives' transaction model on members' chemical pesticide reduction behaviour, an ex-post facto analysis framework must be constructed using the estimated coefficients from the ESR model. The average treatment effect of the farmer cooperatives' transaction model on members' chemical pesticide reduction behaviour is estimated by comparing the expected levels of chemical pesticide reduction behaviour between transactional and non-transactional members in the actual scenario versus the counterfactual scenario.

Expected chemical pesticide reduction levels for members adopting the farmer cooperatives' transaction model:

$$E[Y_{ia} | A_i = 1] = \beta'_a X_{ia} + \sigma_{\mu a} \lambda_{ia} \quad (2)$$

Expected chemical pesticide reduction levels among members not opting for the farmer cooperatives' transaction model:

$$E[Y_{in} | A_i = 0] = \beta'_n X_{in} + \sigma_{\mu n} \lambda_{in} \quad (3)$$

Expected chemical pesticide reduction behaviour levels for farmer cooperatives' transaction model members if they had not selected the transaction model:

$$E[Y_{in} | A_i = 1] = \beta'_n X_{ia} + \sigma_{\mu n} \lambda_{ia} \quad (4)$$

Expected chemical pesticide reduction behaviour level for members not opting for the farmer cooperatives' transaction model when choosing the transaction model:

$$E[Y_{ia} | A_i = 0] = \beta'_a X_{in} + \sigma_{\mu a} \lambda_{in} \quad (5)$$

By comparing Equations 2, 4, 6 can be derived. This represents the average treatment effect (ATT) of the actual choice of the farmer

cooperative transaction model on members' pesticide reduction practices. Its formula is:

$$ATT_i = E[Y_{ia} | A_i = 1] - E[Y_{in} | A_i = 1] = (\beta'_a - \beta'_n) X_{ia} + (\sigma_{\mu a} - \sigma_{\mu n}) \lambda_{ia} \quad (6)$$

By comparing Equations 3, 5, 7 can be derived. The average treatment effect for pesticide reduction practices among members not opting for the farmer cooperative trading model—that is, the average treatment effect (ATU) for the control group. Its formula is:

$$ATU_i = E[Y_{in} | A_i = 0] - E[Y_{ia} | A_i = 0] = (\beta'_n - \beta'_a) X_{in} + (\sigma_{\mu n} - \sigma_{\mu a}) \lambda_{in} \quad (7)$$

### 3.2.2 The mediation model

To further validate the transmission mechanism of the cooperatives' transaction model on members' chemical pesticide reduction behaviour, this study employs a multiple mediation model for analysis. The mediation effect model is specified as follows:

$$y_i = \beta_0 + \beta_1 x_i + \sum_{j=1}^m \beta_2 \text{control}_{ij} + \varepsilon_i \quad (i=1,2,\dots,n; j=1,2,\dots,m) \quad (8)$$

$$\text{med}_i = c_0 + c_1 x_i + \sum_{j=1}^m c_2 \text{control}_{ij} + \varepsilon_i \quad (i=1,2,\dots,n; j=1,2,\dots,m) \quad (9)$$

$$y_i = d_0 + d_1 x_i + d_2 \text{med}_i + \sum_{j=1}^m d_3 \text{control}_{ij} + \varepsilon_i \quad (i=1,2,\dots,n; j=1,2,\dots,m) \quad (10)$$

In Equation 8  $x_i$  denotes the binary choice variable indicating whether a member opts for the farmer cooperatives' transaction model. In Equation 10  $y_i$  denotes members' chemical pesticide reduction behaviour. In Equation 9  $\text{med}_i$  denotes the mediating variable.  $\text{control}_{ij}$  denotes the control variable.  $\varepsilon_i$  denotes the residual (Table 1).

### 3.3 Variable definitions and descriptive statistics

- (1) Dependent variable. Within the specific context of farmer cooperatives development in China and based on the research team's fieldwork, farmer cooperatives' transaction model primarily encompass the following forms: Firstly, farmers join the farmer cooperatives, which centrally organises the production, processing, and marketing of agricultural products (Xu et al., 2017); Secondly, members purchase agricultural inputs or other production services from the farmer cooperatives, which then assists members in selling their agricultural products (Wei and Zhang, 2013); Third, members and the farmer

TABLE 1 Variable selection and assignment notes.

Variable name	Assignment explanation	Total sample	Transaction members	Non-transaction members	Difference
		Mean	Mean	Mean	
<b>Dependent variable</b>					
Chemical pesticides reduction behaviour	Logarithm of the proportion of members reducing chemical pesticides application compared to the previous year	1.489	1.636	1.093	-0.542***
<b>Independent variable</b>					
Farmer cooperatives' transaction model	Whether members transact agricultural products through the farmer cooperatives: Yes = 1; No = 0	0.727	—	—	—
<b>Control variables</b>					
Age	Actual age (years)	56.380	56.097	57.132	1.035
Education	Logarithm of years of education	1.992	2.063	1.800	-0.263
Experience of working away from home	Whether a migrant worker: 1 = Yes; 0 = No	0.559	0.579	0.506	-0.073
Health	Physical Health Status (1–5, increasing health levels)	4.176	4.187	4.145	-0.043
Proportion of agricultural income	Ratio of agricultural sales revenue to total household income	0.427	0.467	0.322	-0.144***
Labor force	Number of household labourers engaged in citrus cultivation (persons)	2.036	2.088	1.897	-0.191**
Cultivation area	Actual Citrus Planting Area (mu)	22.771	26.694	12.322	-14.371***
Awareness of chemical pesticides residue standards	Awareness of government-published maximum residue limits: 1 = Yes; 0 = No	0.564	0.653	0.325	-0.328***
Enhancing environmental awareness	Green production behaviour can significantly improve the environment: increasing recognition levels from 1 to 5	3.780	3.882	3.506	-0.376***
Distance from home to farmer cooperatives	Logarithm of the distance from home to farmer cooperatives	0.928	0.850	1.136	0.286***
Level of agricultural input market development	Development level of the agricultural supplies market in this township: (Levels 1–5, increasing)	2.961	2.914	3.084	0.170***

(Continued)

TABLE 1 (Continued)

Variable name	Assignment explanation	Total sample	Transaction members	Non-transaction members	Difference
		Mean	Mean	Mean	
Regional variable	1 = Chengdu Plain Economic Zone; 2 = North-Eastern Sichuan Economic Zone; 3 = South Sichuan Economic Zone	1.807	1.925	1.493	-0.431***
Group effect	Proportion of members within the same village choosing the farmer cooperatives' transaction model	0.731	0.895	0.692	-0.203
<b>Moderator variable</b>					
Production factor constraints	Whether chemical pesticides were purchased in accordance with farmer cooperatives regulations: Yes = 1; No = 0	0.605	0.678	0.409	-0.269***
Product standard constraints	Whether product compliance with quality certification standards is required: Yes = 1; No = 0	0.533	0.610	0.325	-0.285***
Surplus distribution incentives	Whether the farmer cooperatives distribute surplus: Yes = 1; No = 0	0.465	0.561	0.210	-0.350***
Production service incentives	Richness of farmer cooperatives information dissemination on green pest control technologies: (1-5, increasing richness)	3.192	3.377	2.698	-0.679***

\*, \*\*, \*\*\* denote significance at the 10, 5, and 1% levels, respectively. The same applies to the table below. Differences were compared using parametric t-tests.

cooperatives agree on the quantity and quality of agricultural products and sign contracts for agricultural product transactions (Chen and Zhou, 2014). If a member engages in any of the above behaviours, this variable is assigned a value of 1; otherwise, it is assigned a value of 0. The sample indicates that 72.69% of members have chosen the farmer cooperatives' transaction model.

- (2) Independent variable. This study defines chemical pesticide reduction behaviour, drawing upon relevant scholarly research (Yan et al., 2021), as the quantity of chemical pesticides reduced by members in agricultural production. The specific question is: 'By what percentage did you reduce the application of chemical pesticides last year?' The text uses the logarithm of the reduction ratio in chemical pesticide application by members to represent this.
- (3) Control variables. Drawing upon existing research findings, this study selected 11 variables across four categories as control variables: respondent personal characteristics, household operational characteristics, green production awareness characteristics, and external environmental characteristics. Among these, personal characteristic variables comprise four variables:

decision-maker age, educational attainment, physical health status, and experience of migrant labour (Ma et al., 2018; Wossen, and Abdoulaye T., Alene A., Haile M.G., Feleke S., Olanrewaju A., Manyong V., 2017). Household operational characteristics comprise three variables: labour force size dedicated to citrus cultivation, proportion of household income derived from agriculture, and citrus cultivation area (Zhang, and Hu R., Shi G., Jin Y., Robson M.G., Huang X., 2015; Xu et al., 2021); Green production awareness characteristics (Du et al., 2021) include two variables: the perception that green production behaviour significantly improve the environment, and awareness of chemical pesticides residue limits; External environment characteristics (Damalas, 2021; Pan et al., 2021) comprised two variables: distance from home to the farmer cooperatives and the level of development of the agricultural input market within the township. An area variable was also included to control for differing impacts arising from economic regional variations.

- (4) Mediating variables. Within the aforementioned theoretical framework, the farmer cooperatives' transaction model influences members' reduced chemical pesticide application behaviour primarily through two mechanisms: a constraining

mechanism regarding product quality requirements and an incentivising mechanism involving value-added product support. The constraint mechanism of product quality requirements primarily encompasses input constraints and delivery standard constraints. The input constraint mechanism is defined in the questionnaire as “whether chemical pesticides are purchased in accordance with farmer cooperatives regulations”; a response of ‘yes’ yields a value of 1, otherwise 0. The product delivery standard constraint mechanism is defined by the questionnaire item “Is product compliance with quality certification standards required?” A response of “Yes” yields a value of 1; otherwise, 0. The incentive mechanism for value-added product support primarily encompasses the surplus distribution incentive mechanism and the production service incentive mechanism. The surplus distribution incentive mechanism is defined by the questionnaire item “Does the farmer cooperatives distribute surplus based on transaction volume?” A response of “Yes” yields a value of 1; otherwise, 0. The production service incentive mechanism is defined by the questionnaire item “The extent to which the farmer cooperatives disseminate information on green pest control technologies,” measured using a five-point Likert scale (1–5 indicating increasing richness).

- (5) Instrumental variables. Social psychology indicates that individual farmer behaviour is influenced by the actions of other individuals within the village ( $\rho$ ), a phenomenon termed the “group effect” (Zou and Fang, 2012). Consequently, this study adopts the research approach of scholars such as Sang et al. (2021), selecting the proportion of members within the same village who choose the farmer cooperatives’ transaction model as an instrumental variable. On the one hand, significant mutual influence exists among various behaviours within the same village; the higher the average proportion of other members within the same village choosing the farmer cooperatives’ transaction model, the greater the probability that the surveyed member will also choose this model. On the other hand, the proportion of the farmer cooperatives’ transaction model chosen at the village level as a whole has no direct relationship with an individual member’s decision to reduce chemical pesticide application. In summary, this study argues that this variable satisfies the conditions of relevance and exogeneity for an instrumental variable. The results of the instrumental variable test will be discussed in the empirical findings and analysis section.

## 4 Empirical results and discussions

### 4.1 Estimation results and analysis

The joint estimation results for the farmer cooperatives’ transaction model selection decision and the members’ chemical pesticides reduction application behaviour model are presented in Table 2. Column (1) in Table 2 shows the estimated factors influencing members’ decision to select the farmer cooperatives’ transaction model, while columns (3) and (4) present the estimated factors affecting chemical pesticide reduction application behaviour among transacting and non-transacting members, respectively. In Table 2, Rho-1 and

Rho-0 denote the correlation coefficients between the error terms of the transaction decision model and the reduced chemical pesticide application behaviour models for both transacting and non-transacting members. The estimated values of the error correlation coefficient Rho-1 are statistically significant at the 1% level, indicating sample selection bias. Members’ choice of the farmer cooperatives’ transaction model is not random but constitutes a “self-selection” decision. This supports the validity of employing an endogenous switching regression model for sample analysis.

The estimation results of the choice equation reveal that the decision to adopt the farmer cooperatives’ transaction model is significantly influenced by members’ physical health status, experience of working away from home, and distance from the farmer cooperatives. Regarding the outcome equation, members’ age, physical health status, citrus cultivation area, and awareness of government-published chemical pesticide residue limits significantly promote reduced chemical pesticide application behaviour.

### 4.2 Analysis of treatment effects

To reflect the impact of farmer cooperatives’ transaction model on members’ chemical pesticide reduction behaviour, the average treatment effect of the farmer cooperatives’ transaction model on members’ chemical pesticide reduction behaviour was further calculated, with results shown in Table 3. Overall, members’ selection of farmer cooperatives’ transaction model exerted a significant positive influence on their chemical pesticide reduction behaviour, significant at the 1% level. The ATT estimation indicates that for members who have opted for the farmer cooperatives’ transaction model, choosing not to participate would result in a 32.74% reduction in their chemical pesticide reduction behaviour. The ATU estimation indicates that for members not opting for the farmer cooperatives’ transaction model, participation would increase their chemical pesticide reduction behaviour by 1.53 times. This result further confirms that the farmer cooperatives’ transaction model significantly promotes enhanced chemical pesticide reduction behaviour among members. Accordingly, H1 is validated.

### 4.3 Analysis of conduction mechanisms

The foregoing research indicates that the farmer cooperatives’ transaction model promotes members’ chemical pesticide reduction behaviour. However, the specific mechanisms through which this model facilitates such behaviour warrant closer examination. This section employs the paramed command to analyse the pathways by which the farmer cooperatives’ transaction model influences farmers’ adoption of green pest control technologies. This analysis focuses on four dimensions: constraints on factor inputs, constraints on product delivery standards, surplus distribution incentives, and production service incentives. The objective is to validate the hypotheses proposed in the theoretical analysis section.

The validation results are presented in Table 4. The findings indicate that the confidence intervals for both the natural indirect effect and the total effect of the farmer cooperatives’ production factor input constraints do not encompass zero. The natural indirect effect is significantly positive at the 1% level, while the total effect is significantly positive at the 5% level. The mediation effect ratio stands at 27.92%, thereby validating Hypothesis H2. The confidence intervals for both the natural indirect effect and the total effect of

TABLE 2 Joint estimation results for the farmer cooperatives' transaction model and members' chemical pesticides reduction behaviour model.

Variable	Decision model (1)	Outcome equation	
		Transaction members (2)	Non-transaction members (3)
Age	0.009 (0.009)	0.022** (0.011)	0.004 (0.015)
Education	0.077 (0.126)	-0.067 (0.160)	-0.192 (0.184)
Health	-0.152*(0.088)	0.352*** (0.109)	-0.043 (0.139)
Migrant work experience	0.391*** (0.147)	0.128 (0.159)	0.031 (0.234)
Proportion of agricultural income	0.317 (0.265)	0.093 (0.239)	0.948** (0.522)
Labor force	-0.056 (0.083)	-0.081 (0.083)	-0.121 (0.143)
Cultivated area	0.002 (0.002)	-0.002* (0.001)	-0.006 (0.005)
Awareness of chemical pesticides residue standards	0.152 (0.162)	0.373** (0.185)	0.071 (0.290)
Environmental improvement awareness	0.084 (0.091)	-0.007 (0.099)	0.036 (0.149)
Distance from farmer cooperatives	-0.334** (0.143)	0.040 (0.177)	0.051 (0.213)
Agricultural input market	-0.055 (0.108)	-0.073 (0.111)	-0.199 (0.170)
Regional variable	Control	Control	Control
Group effect	3.678*** (0.367)		
Constant term	-2.071** (0.991)	-0.866 (1.097)	1.586 (1.621)
Athrho-1		-0.612*** (0.163)	
Rho-1		-0.545*** (0.115)	
Athrho-0			-0.148*** (0.263)
Rho-0			-0.147 (0.258)
LR test of independent equations		13.24***	

Figures in parentheses denote corresponding robust standard errors.

TABLE 3 Average treatment effects of the farmer cooperatives' transaction model on members' chemical pesticides reduction behaviour.

Member category	Participating in transactions	Non-participating	ATT	ATU
Transaction member	1.625 (0.025)	1.094 (0.023)	0.532*** (0.044)	—
Non-transaction members	2.395 (0.041)	0.919 (0.022)	—	1.410*** (0.045)

the farmer cooperatives' product delivery standard constraints encompassed non-zero values. The natural indirect effect was significantly positive at the 1% level, while the total effect was significantly positive at the 5% level. The mediation effect ratio stood at 39.93%, thereby validating Hypothesis H3. The confidence intervals for both the natural indirect effect and total effect of farmer cooperatives' surplus distribution incentives did not include zero. The natural indirect effect was significantly positive at the 1% level, while the total effect was significantly positive at the 5% level. The mediation effect ratio was 46.24%, confirming Hypothesis H4. The confidence intervals for both the natural indirect effect and the total effect of farmer cooperatives' production service incentives did not include zero. The natural indirect effect was significantly positive at the 1% level, while the total effect was significantly positive at the 5% level. The mediation effect ratio was 25.83%, confirming hypothesis H5.

### 4.4 Heterogeneity analysis

Different external transaction partners of farmer cooperatives convey distinct quality signals. Under varying quality signals, farmer cooperatives guide members' production behaviours through governance mechanisms aligned with differing collective objectives. This study categorises farmer cooperatives' transaction model based on citrus sales partners: "Farmer cooperatives + Company," "Farmer cooperatives + Fruit Merchant," and "Farmer cooperatives + E-commerce." Considering sample size and data availability, we further examine the treatment effects of different farmer cooperatives' transaction models on members' chemical pesticide reduction behaviour. Estimation results are presented in Table 5.

The validation results are presented in Table 5. The ATT estimates indicate that for members who have opted for the farmer cooperatives + company model, choosing not to participate would reduce their

TABLE 4 Transmission mechanism tests.

Category	Effect	Estimated coefficient	Standard error	Probability value	Confidence interval	Natural indirect effect/total effect (%)
Production factor input constraints	Treatment direct effect	0.239	0.156	0.126	-0.067 ~ 0.547	27.92%
	Natural indirect effect	0.093	0.034	0.007***	0.025 ~ 0.161	
	Total effect	0.333	0.156	0.033**	0.026 ~ 0.640	
Product delivery standard constraints	Processing direct effects	0.200	0.154	0.196	-0.103 ~ 0.503	39.93%
	Natural indirect effect	0.133	0.042	0.001***	0.051 ~ 0.215	
	Total effect	0.333	0.156	0.033**	0.026 ~ 0.640	
Profit distribution incentive	Direct effect processing	0.178	0.158	0.259	-0.131 ~ 0.488	46.24%
	Natural indirect effect	0.154	0.045	0.001***	0.066 ~ 0.243	
	Total effect	0.333	0.156	0.033**	0.026 ~ 0.640	
Production service incentives	Processing direct effect	0.246	0.156	0.114	-0.589 ~ 0.552	25.83%
	Natural indirect effect	0.086	0.033	0.009***	0.021 ~ 0.151	
	Total effect	0.333	0.156	0.033**	0.026 ~ 0.640	

chemical pesticide reduction behaviour by 57.6%. The ATU estimates indicate that for members not selected by this model, choosing to participate would increase their chemical pesticide reduction behaviour by 1.34 times. The ATT estimates show that for members who have selected the farmer cooperatives + wholesale market/wholesaler model, choosing not to participate would decrease their chemical pesticide reduction behaviour by 43.4%. ATU estimates indicate that for members not selecting this model, participation would increase chemical pesticide reduction behaviour by 2.26 times. ATT estimates show that for members already selecting the farmer cooperatives + e-commerce model, non-participation would decrease chemical pesticide reduction behaviour by 44.3%. ATU estimates indicate that for members not opting for this model, participation would increase chemical pesticide reduction behaviour by 0.89 times.

Heterogeneity analysis reveals that the 'farmer cooperative + company' model yields the most pronounced effects, likely because this transactional approach typically manifests as stable contract farming or vertically integrated partnerships. Such arrangements generally involve stringent process controls and prioritise pesticide residue as a core testing metric. Concurrently, to guarantee raw material quality, companies frequently provide technical guidance, specialised inputs, and premium pricing commitments, offering sustained economic incentives for members to reduce pesticide usage. In contrast, the 'farmer cooperative + e-commerce' model primarily relies on market reputation mechanisms. E-commerce platforms transparently relay consumer preferences and evaluations of green products to producers, prompting cooperatives to proactively implement internal standards to safeguard brand reputation. However, technical support for production remains limited. The 'farmer cooperative + fruit merchant' model

represents loose traditional market transactions, where fruit merchants primarily convey incentives through fluctuating market price signals. Lacking stable contracts and direct support, this model is highly susceptible to market conditions, exhibiting the weakest stability and systemic integrity.

## 4.5 Robustness test

The dependent variable in this study is members' chemical pesticide reduction behaviour, which is continuous data. Therefore, the CMP and 2SLS models were employed to test the robustness of the regression results from the aforementioned model. As shown in Table 6, the CMP model results indicate that the farmer cooperatives' transaction model exerts a significant positive influence on members' chemical pesticide reduction behaviour. This suggests that the regression results from the ESR model are relatively robust, and the conclusions are reasonably reliable.

## 5 Conclusions and policy implications

This study employs an endogenous switching regression (ESR) model and mediation analysis models to systematically examine the impact of farmer cooperatives' transaction modes on members' chemical pesticide reduction behaviour and their underlying mechanisms, based on field survey data from 608 citrus farmer cooperatives members in Sichuan Province. It further distinguishes heterogeneous effects across different external transaction counterparts. Key findings

TABLE 5 Estimated overall effects of farmer cooperatives' external transaction contracts on members' chemical pesticides reduction behaviour.

Member category	Transacting members	Non-transacting members	ATT	ATU
Select the "Farmer cooperatives + Company" transaction model	1.710 (0.032)	1.133 (0.030)	0.576*** (0.053)	
Do not select the "farmer cooperatives + company" transaction model	2.361 (0.042)	1.019 (0.020)		1.342*** (0.042)
Opting for the "farmer cooperatives + wholesale market/wholesaler" transaction model	1.483 (0.033)	1.049 (0.068)	0.434*** (0.068)	—
Do not select the "farmer cooperatives + wholesale market/wholesaler" transaction model	2.313 (0.059)	0.045 (0.060)		2.268*** (0.103)
Opting for the 'farmer cooperatives + e-commerce' transaction model	1.667 (0.040)	1.223 (0.032)	0.443*** (0.059)	—
Do not select the "farmer cooperatives + e-commerce" transaction model	1.859 (0.043)	0.959 (0.047)		0.899*** (0.072)

TABLE 6 Robustness test.

Variable	CMP model	2SLS model
Farmer cooperatives' transaction model	1.463*** (0.290)	1.406*** (0.297)

Control variables	Controlled	Controlled
/lnsig_2	0.473*** (0.035)	
/lnsig_2	-1.090*** (0.028)	
atanrho_12	-0.356*** (0.073)	
Log likelihood	-1308.248	
LRchi <sup>2</sup> /	400.38	
Kleibergen-Paap rk LM statistic		179.502***
Cragg-Donald Wald F statistic		249.158***
F statistic/chi-squared		34.68***

are as follows: Firstly, farmer cooperatives' transaction modes significantly promote members' chemical pesticide reduction behaviour. Results indicate that members who adopt the farmer cooperatives' transaction model would exhibit a 32.74% reduction in chemical pesticide reduction behaviour if non-participants; conversely, non-participants who opt to join would see a 1.53-fold increase in such behaviour, validating Hypothesis H1. Second, the mechanism analysis indicates that the farmer cooperatives' transaction model influences

members' chemical pesticide reduction behaviour through four pathways, ranked by contribution rate from highest to lowest: surplus distribution incentives (46.24%), product delivery standard constraints (39.93%), production factor input constraints (27.92%), and production service incentives (25.83%). Hypotheses H2 to H5 are all validated; Thirdly, heterogeneity analysis reveals significant differences in the impact of farmer cooperatives' transaction model with various external entities on chemical pesticide reduction behaviour. The "farmer cooperatives + company" model demonstrates the most pronounced enhancement effect (ATT of 57.6%), followed by "farmer cooperatives + e-commerce" (44.3%) and "farmer cooperatives + fruit trader" (43.4%). This indicates that collaboration with market entities characterised by high standardisation and stringent quality requirements provides stronger incentives for farmer cooperatives to enhance internal green production management.

Based on these findings, this paper proposes four policy recommendations to better leverage farmer cooperatives as organisational vehicles for advancing agricultural green transformation. First, strengthen internal governance mechanisms within farmer cooperatives by refining institutional designs that balance incentives and constraints. Prioritise guiding farmer cooperatives to establish distribution systems explicitly linking green production performance to surplus returns, thereby directly translating pesticide reduction into economic benefits. Simultaneously, clarify product delivery standards and regulations for the use of production materials, forming a closed-loop system combining 'soft incentives' with 'hard constraints' to efficiently guide members' production behaviour transformation. Second, facilitate connections between farmer cooperatives and diverse market entities to expand sales channels for high-quality agricultural products. Key emphasis should be placed on encouraging and supporting farmer cooperatives to enter into long-term production-marketing agreements with leading agricultural enterprises and supermarkets.

Leveraging these partners' stringent quality standards and stable orders will compel farmer cooperatives to standardise and green their internal production management. Thirdly, enhance the service functions of farmer cooperatives to accelerate the adoption of green production technologies. Farmer cooperatives should be encouraged to conduct green production training and centralise the supply of inputs and agricultural materials. This reduces the cost and uncertainty of adopting green technologies for members, strengthening their willingness and capacity to reduce chemical inputs. Fourthly, emphasise the demonstration effect within villages to foster a collective atmosphere for green production. Policies should focus on cultivating core members as 'model households' and, through farmer cooperative-organised field demonstrations and experience-sharing activities, disseminate successful green production practices via neighbourhood social networks. This 'group effect' will drive the overall transformation of smallholder farmers.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Author contributions

RZ: Conceptualization, Writing – original draft, Writing – review & editing. KZ: Supervision, Writing – review & editing. FF: Writing – review & editing, Data curation. YC: Writing – review & editing, Data curation, Investigation, Software. GZ: Writing – review & editing, Supervision, Project administration, Investigation. CY: Writing – original draft, Writing – review & editing, Methodology, Formal analysis, Conceptualization.

## Funding

The author(s) declared that financial support was received for this work and/or its publication. This work was supported by the Sichuan Academy of Social Sciences' institutional research project (Grant No.

23RCYJ07) and the National Social Science Foundation of China (Grant No. 23XJY010). Research Team on the Theory of Chinese-Style Agricultural and Rural Modernisation and Its Implementation in Sichuan: Funding Outcomes from the Sichuan Academy of Social Sciences.

## Acknowledgments

We want to thank the heads of the units who helped us in the survey, and the leaders and members of the cooperatives who actively participated in our questionnaire.

## Conflict of interest

The author(s) declared that this work 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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