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ORIGINAL ARTICLE

Cooperative membership and adoption of green pest control practices: Insights from rice farmers

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Abstract

Reducing the use of chemical pesticide while preserving crop yield is a practical strategy that makes agricultural production economically, socially and environmentally sustainable. Although the adoption of green pest control practices can help achieve such a goal, its adoption rate remains quite low. This study explores whether membership in agricultural cooperatives improves smallholder farmers' adoption of green pest control practices, utilising farm-level data surveyed from rice farmers in China. To enrich our understanding, we also investigate how the adoption of green pest control practices mediates the effects of cooperative membership on chemical pesticide expenditures. An endogenous switching probit model and a bootstrap-based mediation method are employed to achieve these goals. The empirical results show that cooperative membership significantly increases the probability of adopting physical pest control practices (e.g. pest-killing lamps or sticky plate traps) and biological pest control practices (e.g. biopesticides) by 6% and 19%, respectively. Cooperative membership significantly reduces chemical pesticide expenditures through its mediation effect on improving the probability of adopting biological pest control practices. There is also a complementary relationship between physical and biological pest control practices in pest management of rice production. The adoption of physical pest control practices significantly increases rice yield, while the adoption of biological pest control practices does not.

KEYWORDS

China, cooperative membership, endogenous switching probit, green pest control, rice farmers

JEL CLASSIFICATION

J54, O14, Q16, Q57

1 | INTRODUCTION

Chemical pesticides such as insecticides, herbicides, fungicides and rodenticides have been widely applied in agricultural production. Nowadays, over 1000 different pesticides have been used worldwide. Although chemical pesticides have helped to increase farm productivity and relieve human drudgery, their extensive usage in farming has caused various health and environmental issues (Lopes-Ferreira et al., 2022; Rani et al., 2021; Sabarwal et al., 2018; Tudi et al., 2021; Voltz et al., 2022). For example, Berg and Tam (2018) investigated Vietnam farmers and found that 85% experienced health-related issues caused by pesticide use. Pesticides used for farm production can also kill birds, fish and beneficial insects, contaminate ground and surface water and pollute air and soil (Aktar et al., 2009). In addition, the overuse of chemical pesticides challenges sustainable food supply and nutrition security for the fast-growing global population. The world's population is expected to reach 9.1 billion by 2050 (34% higher than today), and food production needs to increase by 70% to meet the growing food demand. Thus, there is a need to explore solutions that reduce chemical pesticide use substantially while sustaining or increasing crop yield in the process of intensifying agricultural production sustainably. This can help achieve the goal of making the agricultural sector more economically, socially and environmentally sustainable.

Scholars from different countries have explored various programmes and practices that may help reduce pesticide use (Bakker et al., 2021; Li et al., 2022; Mir et al., 2022; Pan et al., 2021; Thomine et al., 2022; Zhao et al., 2021). For example, Li et al. (2022) found that crop insurance, as an effective risk management tool, motivates insured rice farmers in China to substitute pesticides with clean production technologies such as green prevention and control technology and organic production technologies. Thomine et al. (2022) suggested that increasing crop diversity would help reduce pesticide use because it optimises resource continuity, such as food and shelter for natural enemies, to increase biocontrol services and to reduce pest outbreaks and crop losses. Lin, Hu, et al. (2022) found that agricultural extension services used by rice farmers in China help reduce pesticide use. Others suggest that encouraging farmers to adopt pesticide-free production standards could be a solution to reduce pesticide use (Jacquet et al., 2022; Möhring & Finger, 2022).

Green pest control practices, including physical pest control practices (e.g. using pest-killing lamps and sticky plate traps) and biological pest control practices (e.g. using biopesticides), are also practical strategies for reducing chemical pesticide use.[1] Although physical and biological pest control practices are both sustainable and eco-friendly, they play different roles in pest management (FAO, 2022). Specifically, physical pest control practices use barriers or traps to directly kill pests or physically keep pests from hosts, which is rapid and effective. In comparison, biological pest control practices use living organisms to naturally kill, prevent or repel pests, which takes a longer time. Despite the significant benefits of physical and biological pest control practices in pest management, their adoption rates remain quite low worldwide.

This study extends the findings of previous studies and explores whether agricultural cooperatives could help increase farmers' adoption of green pest control practices. In developing countries such as China, Zambia, Ethiopia and India, agricultural cooperatives play a non-negligible role in promoting sustainable rural development (Blekking et al., 2021; Gava et al., 2021), boosting farm economic sustainability (Candemir et al., 2021; Lin,

[1]Adopting green pest control practices is expected to reduce chemical pesticide use while preserving crop yield, and it may also lead to potential water and land pollution and yield reduction if its application exceeds the requirement.

Wang, et al., 2022) and improving rural farmers' mental health and subjective well-being (Liang et al., 2022; Wu et al., 2022). When it comes to agricultural technology adoption, agricultural cooperatives provide technical training and improve farmers' farm management skills, motivating them to adopt innovative technologies (Ma et al., 2022). Based on the information received from cooperatives, members would also have a higher awareness of the potential benefits of innovative technologies than nonmembers (Mishra et al., 2018). Some studies have found positive linkages between agricultural cooperatives and farmers' adoption of agricultural technologies such as fertilisers and improved seeds (Abebaw & Haile, 2013; Li, Liu, et al., 2021; Manda et al., 2020; Wossen et al., 2017; Zhang, Sun, et al., 2020). For example, Manda et al. (2020) showed that cooperative membership increases the likelihood of adopting improved maize, inorganic fertiliser and crop rotation in Zambia.

Although agricultural cooperatives play a significant role in facilitating technology adoption, their ability to influence smallholder farmers' adoption of environmentally friendly practices has received little attention in the literature. Only a few studies explored the role of agricultural cooperatives in promoting the adoption of green control practices (Li, Liu, et al., 2021; Liu et al., 2022; Yu et al., 2021; Zhang et al., 2023). Yu et al. (2021) found that cooperative membership encourages vegetable farmers in the Shandong province of China to adopt green control practices because it helps farmers to avoid adoption risks. The positive impact of cooperative membership on the adoption of green control practices is further verified by Li, Liu, et al. (2021) in their investigation of rice farmers in the Sichuan province and by Zhang et al. (2023) who investigated vegetable and fruit growers in the Shandong province. Liu et al. (2022) investigated 837 citrus producers in the Sichuan Province of China and found that the technical training provided by agricultural cooperatives increases the probability of adopting biopesticides among smallholder farmers. Although the findings of these studies offer insights regarding the role of cooperative membership in the adoption of green control practices, they did not distinguish the differences between physical and biological pest control practices. In addition, the analysis of the previous studies has relied on data collected from one province, narrowing the representativeness of the findings.

This study aimed to examine the impact of agricultural cooperative membership on farmers' adoption of green pest control practices, distinguishing physical and biological pest control practices. We analyse data collected from farmers producing rice in five provinces (Hubei, Henan, Hunan, Jiangsu and Sichuan) in China. In doing so, we make four contributions to the existing literature. First, we utilise an endogenous switching probit (ESP) model to address the potential selection bias originating from observed and unobserved factors when estimating the association between cooperative membership and green pest control practices. The ESP model also allows us to investigate factors motivating farmers' decision to have cooperative membership, explore factors affecting decisions to adopt green pest control practices and estimate the treatment effects of cooperative membership (Haile et al., 2020; Li et al., 2020). Second, we examine the potential mediating roles of physical and biological pest control practices in explaining the impact of cooperative membership on chemical pesticide expenditures. Third, we investigate whether physical pest control practices substitute or complement biological pest control practices in rice production, given that they play a similar role in reducing chemical pesticides use. Finally, we estimate how the adoption of physical and biological pest control practices affects rice yield.

The rest of the paper is organised as follows. Section 2 introduces the background and econometric strategies. Data collection and descriptive statistics are presented in Section 3. Section 4 presents and discusses the empirical results. The final section concludes the paper and proposes the policy implications.

2 | BACKGROUND AND ECONOMETRIC STRATEGY

2.1 | Background

2.1.1 | Pesticide use in China

In China, there were 1.77 million tonnes of pesticides used for agricultural production in 2019, ranking the highest globally (FAOSTAT). The quantity of pesticide use in China is remarkably higher than other major pesticide-using countries such as the United States, Brazil and Argentina, each consuming 0.4, 0.37 and 0.2 million tonnes, respectively (FAOSTAT). In China, herbicides are the main type of pesticide used in production, accounting for 52.84% of the total pesticide consumption (Figure 1). China is also the largest rice-producing country globally, with a total output of 213.61 million tonnes in 2021 (FAOSTAT). However, rice production was largely driven by the increased use of chemical inputs like fertilisers and pesticides. For example, it is reported that the average expenditure on pesticides in rice production increased from 51.16 yuan/mu (116.10 USD/ha) to 60.79 yuan/mu (137.95 USD/ha) from 2015 to 2020 (NCAPCI, 2021). The Chinese government has implemented an "Action plan" since 2015 to control undue chemical pesticide application (Ma & Zheng, 2022). Both physical and biological pest control practices could substitute or supplement chemical pesticide applications and potentially reduce chemical pesticide expenditures. The survey data collected from China's rice industry provide an interesting case to investigate the impact of cooperative membership on farmers' adoption of green pest control practices and its subsequent effects on chemical pesticide expenditures and rice yield.

2.1.2 | Study site

We chose Hubei, Henan, Hunan, Jiangsu and Sichuan provinces as survey areas. The selected five provinces notably differ in natural endowment and economic development levels. Among the five provinces, Jiangsu, Hubei and Sichuan cover Eastern, Central and Western China, respectively, while Henan and Hunan range from northern to southern China. The annual precipitation is 800–1600 millimetres (mm) in Hubei, 400–1290 mm in Henan, 1300–1600 mm in Hunan, 1000–1300 mm in Jiangsu and 700–1250 mm in Sichuan. The per capita disposable incomes were 18,259 yuan in Hubei, 17,533 yuan in Henan, 18,295 yuan in Hunan, 26,791 yuan in Jiangsu and 17,575 yuan in Sichuan in 2021 (1 USD = 6.61 Yuan; 1 AUD = 4.65 Yuan) (NBSC, 2022). Overall, the heterogeneity across the five provinces would increase the generality of the relevant findings. In 2021, the rice production in the five provinces was 85.21 million tonnes, accounting for 40.03% of the total national rice production (NBSC, 2022). Reducing rice yield loss caused by pests is

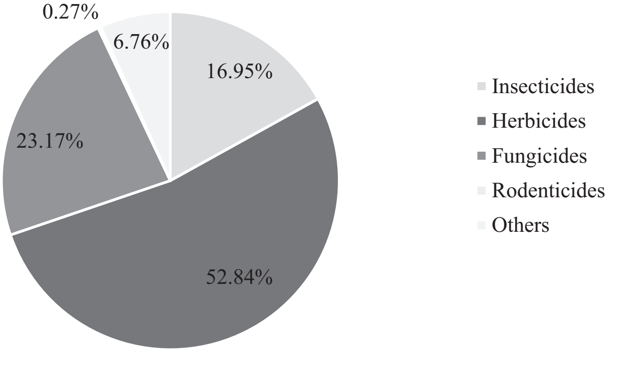

FIGURE 1 Distributions of major types of pesticides in China. *Source*: FAOSTAT 2019.

crucial for improving the livelihoods of rice-producing farmers, especially those who rely on farm income from rice production for livelihoods. Thus, the survey data collected from rice farm households in the selected five provinces are nationally representative to some extent.

2.2 | Econometric strategies

2.2.1 | Selection bias issues and model selection

Given that farmers decide whether to adopt green pest control practices, their technology adoption decisions can be measured as a dichotomous variable. In particular, the relationship between green pest control practice adoption and cooperative membership and other control variables can be assumed as follows:

$$P_i^* = \alpha C_i + \beta X_i + \varepsilon_i, \quad \text{where} \quad P_i = \begin{cases} 1 \text{ if } P_i^* > 0 \\ 0 \text{ otherwise} \end{cases} \tag{1}$$

where P_i^* is a latent variable denoting the probability that a farmer i adopts green pest control practices (physical or biological pest control practices in this study), which cannot be observed directly. Instead, P_i^* is determined by an observable dichotomous variable P_i. Specifically, P_i takes the value of one if the farmer i adopts green pest control practices and zero otherwise. C_i is a binary variable indicating a farmer's cooperative membership status (1 = cooperative member and 0 = nonmember); X_i is a vector of control variables that are expected to affect a farmer's adoption decision on green pest control practices; α and β are parameters to be estimated, and ε_i is an error term with zero means.

Under the exogenous assumption of variable C_i, we can employ a probit or logit regression model to estimate Equation (1) and obtain estimates regarding the effects of cooperative membership on the adoption of green pest control practices, which is captured by the parameter α. However, farmers' decisions to participate in agricultural cooperatives are not randomly observed. Previous studies suggest that farmers voluntarily join agricultural cooperatives, which results in self-selection bias issues (Olagunju et al., 2021; Ortega et al., 2019). Therefore, addressing these issues is essential when estimating the relationship between cooperative membership and the adoption of green pest control practices.

When estimating the effect of a binary treatment variable (i.e. cooperative membership) on binary outcome variables (adoption of physical or biological pest control practices), several econometric methods could be used to correct for selection bias. These include the propensity score matching (PSM; Banga, 2022; Shimada & Sonobe, 2021), inverse-probability weighted regression adjustment (IPWRA) estimator (Manda et al., 2018; Zheng & Ma, 2021), recursive bivariate probit (RBP) model (Li, Cheng, & Shi, 2021; Owusu et al., 2021; Zheng et al., 2021) and the endogenous switching probit (ESP) model (Haile et al., 2020; Li et al., 2020). This study employs the ESP model for two reasons. First, the ESP model accounts for selection bias issues simultaneously generated by observed characteristics (e.g. age and education status of decision-makers and household wealth level) and unobserved heterogeneities (e.g. a farmer's ability and motivation). The PSM and IPWRA models only address observed selection bias, ignoring unobserved selection bias. Second, the ESP model simultaneously estimates three equations, including one selection equation and two outcome equations (one for cooperative members and another for nonmembers), providing more granular insights into the factors affecting a farmer's decision to join a cooperative and adopt green pest control practices. Although the RBP model also addresses observed and unobserved selection bias issues, it only estimates one selection equation and one outcome equation, providing relatively few insights.

2.2.2 | Endogenous switching probit model

The ESP model comprises three-stage estimations. The first stage estimates the selection equation, modelling a farmer's decision to join an agricultural cooperative. To maximise utility, farmers would only join an agricultural cooperative if the utility derived from the membership exceeds that from nonmembership. The probability that a farmer would join an agricultural cooperative is estimated using a probit model, which can be expressed as follows:

$$C_i^* = \gamma Z_i + \mu_i, \quad \text{where} \quad C_i = \begin{cases} 1 \text{ if } C_i^* > 0 \\ 0 \text{ otherwise} \end{cases} \tag{2}$$

where C_i^* is a latent variable representing the probability that a farmer i decides to join an agricultural cooperative. Similarly, the observed C_i determines the unobserved C_i^* and is defined as a binary variable (1 = cooperative member and 0 = nonmember); Z_i refers to a vector of exogenous variables related to the farmer's decision to join a cooperative. γ is a vector of unknown parameters to be estimated; and μ_i is an error term with zero mean.

The second stage of the ESP model investigates the factors affecting the farmers' decisions to adopt green pest control practices. The two outcome equations, based on the membership status, are given as follows:

$$P_{1i}^* = \theta_1 X_{1i} + \xi_{1i}, P_{1i} = \begin{cases} 1 \text{ if } P_{1i}^* > 0 \\ 0 \text{ otherwise} \end{cases} \quad \text{for} \quad C_i = 1 \tag{3a}$$

$$P_{0i}^* = \theta_0 X_{0i} + \xi_{0i}, P_{0i} = \begin{cases} 1 \text{ if } P_{0i}^* > 0 \\ 0 \text{ otherwise} \end{cases} \quad \text{for} \quad C_i = 0 \tag{3b}$$

where P_{1i}^* and P_{0i}^* are two latent variables denoting the probabilities of adopting green pest control practices for cooperative members and nonmembers, respectively. The corresponding observed adoption status P_{1i} and P_{0i} equal one if a farmer i adopts the physical or biological pest control practices, and zero otherwise; X_{1i} and X_{0i} are vectors of explanatory variables; θ_1 and θ_0 are vectors of parameters to be estimated; and ξ_{1i} and ξ_{0i} are error terms.

Equations (2), (3a) and (3b) are estimated jointly using the full information maximum likelihood (FIML) estimator with the Stata command "*switch_probit*" (Lokshin & Sajaia, 2011). The error terms, μ_i, ξ_{1i} and ξ_{0i} are assumed to be jointly normally distributed, with a zero-mean and following correlation matrix:

$$\Omega = \begin{pmatrix} 1 & \rho_0 & \rho_1 \\ & 1 & \rho_{10} \\ & & 1 \end{pmatrix} \tag{4}$$

where ρ_0 is the correlation between μ_i and ξ_{0i}, ρ_1 is the correlation between μ_i and ξ_{1i}, and ρ_{10} is the correlation between ξ_{1i} and ξ_{0i}. The parameters ρ_0 and ρ_1 reflect the extent to which cooperative membership influences a farmer's decision to adopt green pest control practices for nonadopters and adopters through unobserved heterogeneities, respectively. Following Lokshin and Sajaia (2011), the log-likelihood function of the three simultaneous systems of Equations (2), (3a) and (3b) can be written as:

$$Ln(\varsigma) = \sum_{C_i \neq 0, P_i \neq 0} \omega_i \ln\left\{\Phi_2\left(\theta_1 X_{1i}, \gamma Z_i, \rho_1\right)\right\} + \sum_{C_i \neq 0, P_i = 0} \omega_i \ln\left\{\Phi_2\left(-\theta_1 X_{1i}, \gamma Z_i, -\rho_1\right)\right\}$$
$$+ \sum_{C_i = 0, P_i \neq 0} \omega_i \ln\left\{\Phi_2\left(\theta_0 X_{0i}, -\gamma Z_i, -\rho_0\right)\right\} + \sum_{C_i = 0, P_i = 0} \omega_i \ln\left\{\Phi_2\left(-\theta_0 X_{0i}, -\gamma Z_i, \rho_0\right)\right\} \quad (5)$$

where ω_i is an optional weight for observation i; and Φ_2 is the cumulative function of the bivariate normal distribution.

Although the control variables in the first and second stages, that is X_i and Z_i can be identical and overlap, an exclusion restriction is required to better identify the ESP model (Haile et al., 2020; Li et al., 2020). In other words, at least one variable should be included in Z_i, but not in X_i. This excluded variable, serving as an instrumental variable (IV), is expected to influence a farmer's decision of having cooperative membership but not directly affect their decisions of adopting green pest control practices. We use a dummy variable indicating the cooperative membership status of survey farmers' relatives or friends (1 = members and 0 = nonmembers). We designed the relevant questions in our survey questionnaire to collect the required information. Supported by the peer effect theory (Eilers et al., 2022; Ferrali et al., 2020), we ascertain that farmers are more likely to join agricultural cooperatives when their relatives or friends are already members. This is because they can observe the benefits of joining cooperatives from their relatives or friends and then imitate the participation decisions. However, we do not expect that a survey farmer's decision to adopt green pest control practices is directly influenced by their relatives' or friends' membership status. Besides, we also empirically verified the validity of the IV using the falsification test (Di Falco et al., 2011). The results (see Table S1 in Appendix) reveal that the IV is a statistically significant driver of the decisions to join agricultural cooperatives (see column 2 of Table S1) but not adopting green pest control practices among farmers that did not participate in agricultural cooperatives (see columns 3 and 4 of Table S1). The test results support the IV can be considered a valid instrument.

2.2.3 | Average treatment effects (ATE)

The ATE of cooperative membership are estimated in the third stage of the ESP model. Technically, the ESP model can calculate the ATE, average treatment effects on the treated (ATT) and the average treatment effects on the untreated (ATU; Lokshin & Sajaia, 2011). To simplify our analysis, we are only interested in calculating the ATE in the present study.

The treatment effect (TE), which is the expected impact of the treatment on farmers with observed characteristics x_i randomly selected from the sample, is specified as follows:

$$\text{TE}\left(x_i\right) = \text{Prob}\left(Y_1 = 1 | C = 1, X = x_i\right) - \text{Prob}\left(Y_0 = 1 | C = 0, X = x_i\right) = F\left(\theta_1 X_1\right) - F\left(\theta_0 X_0\right) \quad (6)$$

where $F(\bullet)$ is the cumulative function of the bivariate normal distribution.

It should be highlighted that the estimated TE in Equation (6) is bias-corrected after accounting for selection bias originating from observed and unobserved factors. The ATE for the whole sample can be calculated as follows:

$$\text{ATE} = \frac{1}{N} \sum_{i=1}^{N} \text{TE}\left(x_i\right) \quad (7)$$

where N refers to the total sample size.

2.2.4 | Mediation analysis

In addition to estimating the treatment effect of cooperative membership on the adoption of green pest control practices, we are also interested in investigating through which channel cooperative membership affects chemical pesticide expenditures. The indirect channel of cooperative membership is potentially through green pest control practices, including physical and biological pest control practices. To uncover these potential mechanisms, we further use the mediation analysis to examine the contributions of two green pest control practices in explaining farmers' behaviours on chemical pesticide expenditures. Following previous studies (MacKinnon et al., 2007; Nie et al., 2021), the equation system for mediation analysis in which the cooperative membership variable C_i affects the chemical pesticide expenditures CPE_i through two mediators, physical pest control practice P_{pi} and biological pest control practice P_{bi}. These relationships are expressed as follows:

$$\mathrm{CPE}_i = a_1 C_i + d_1 X_i + \upsilon_{1i} \tag{8}$$

$$\mathrm{CPE}_i = a_2 C_i + b_1 P_{pi} + b_2 P_{bi} + d_2 X_i + \upsilon_{2i} \tag{9}$$

$$P_{pi} = a_3 C_i + d_3 X_i + \upsilon_{3i} \tag{10}$$

$$P_{bi} = a_4 C_i + d_4 X_i + \upsilon_{4i} \tag{11}$$

where a_1, a_2, a_3, a_4, b_1, b_2, d_1, d_2, d_3 and d_4 are parameters to be estimated; υ_{1i}, υ_{2i}, υ_{3i} and υ_{4i} are error terms. The mediation analysis decomposes the total effects into the sum of the direct effects and the indirect effects (Liao et al., 2020; Nie et al., 2021; Zhang, Mishra, et al., 2020). In Equations (8)–(11), a_1 is the total effect of cooperative membership on chemical pesticide expenditures. a_2 is the direct effects of cooperative membership on chemical pesticide expenditures after controlling for the two mediators (P_{pi} and P_{bi}) and other control variables (X_i). b_1 and b_2 are the coefficients of two mediators of chemical pesticide expenditures adjusted by cooperative membership. It should be kept in mind that b_1 and b_2 do not represent indirect effects because Equations (10) and (11) show that the two mediators are also influenced by cooperative membership.

The Sobel test and bootstrapping-based method are usually used to examine the mediation effects (Preacher & Hayes, 2008; Zhang, Mishra, et al., 2020). Compared with the Sobel test, the bootstrap-based method could increase the accuracy of confidence intervals for the indirect effects because it owns substantial advantages of no limitation on sample size and broad applicability (Zhang, Sun, et al., 2020). We therefore employ the bootstrapping-based method in this study to test the indirect effects of physical and biological pest control practices on chemical pesticide expenditures. The bootstrapping procedure proceeds as follows. First, we bootstrap the sample distribution of specific and total indirect effects by extracting a sample size n from the original sample with replacement. Then, the process is repeated m times. We follow Nie et al. (2021) and set m as 5000. The 5000-times bootstrapping procedure estimates confidence intervals' upper and lower cut-offs for specific and total indirect effects. We bootstrap both the percentile (P) and bias-corrected (BC) confidence intervals because the small sample size in this study may not satisfy the normality assumption of sample distribution (Nie et al., 2021; Zhang, Mishra, et al., 2020). The estimated confidence intervals identify the significance of mediation effects. Specifically, when the confidence intervals do not cross zero, the mediation effects can be considered significant (Hilbrecht et al., 2014).

3 | DATA COLLECTION AND DESCRIPTIVE STATISTICS

3.1 | Data collection

The data are from a rural household survey of rice farmers in China conducted between January and February 2022. We used a stratified random sampling procedure. After selecting those five provinces in the first stage, in the following two stages we randomly selected 8–10 counties from each chosen province and then chose about 1–2 villages from each selected county. Finally, we randomly selected approximately ten households in each chosen village. The survey results show that not all respondents cultivated rice in 2021. Therefore, we dropped respondents without rice production. Further, we dropped respondents with missing and extreme values in the key variables. The final dataset for this study includes 432 respondents.

The questionnaire included modules on individual-level and household-level characteristics (e.g. age, gender and household size), rice production (e.g. inputs, technology adoption and output) and locational characteristics. Respondents were asked to identify whether they had adopted physical and biological pest control practices in rice production. The main dependent variables, physical and biological pest control practices, are binary variables, which take the value of one if farmers have adopted corresponding practices and zero otherwise. Chemical pesticide expenditures and rice yield are also used as dependent variables for additional analysis. We measure chemical pesticide use in monetary value (i.e. expenditures) rather than in quantity because, in reality, liquid and powder pesticides are also used by farmers. Rice yield is measured at kilogram per mu. The treatment variable, cooperative membership, is defined as a dichotomous variable that equals one for cooperative members and equals zero for nonmembers.

3.2 | Descriptive statistics

Table 1 presents the definition and descriptive statistics of selected variables and reports the mean comparisons between cooperative members and nonmembers. About 12% of respondents have adopted physical pest control practices, and 9% have adopted biological pest control practices (see column 3 of Table 1). Farmers spent, on average, 77.76 yuan/mu (176.46 USD/ha) on chemical pesticides. Table 1 reveals that about 10% of respondents participated in agricultural cooperatives that mainly provided production services. Regarding individual- and household-level characteristics, the respondents reported that their household heads' average age was 54.11 years old, with an educational experience of 6.89 years. About 65% of households were headed by males. In terms of health status, household heads were generally in good health condition, with a score of 3.97 out of five. About five members lived together in households, 37% of them participated in off-farm work, and 16% were the child who aged 15 years old or younger. The average land size for rice cultivation among households was 8.16 mu. About 11% of households experienced insect damage, while 25% owned microwave oven(s). The mean differences between cooperative members and nonmembers are presented in the last column of Table 1. It shows that cooperative members are statistically different from nonmembers regarding the outcome and independent variables. For example, cooperative members are more likely to adopt biological pest control practices than nonmembers. And there are also systematic differences in farm size and provincial locations across cooperative members. Nevertheless, these considerable differences highlight the essence of employing econometric methods like the ESP model to estimate the effects of cooperative membership on the adoption of green pest control practices.

TABLE 1 Definition and descriptive statistics of variables.

Variable	Definitions	Overall ($n = 432$) Mean (SD)	Members ($n = 43$) Mean (SD)	Nonmembers ($n = 389$) Mean (SD)	Mean difference
Outcome variables					
Physical pest control	1 if a farmer adopted physical pest control practices (e.g. pest-killing lamp or sticky plate trap) in rice production, 0 otherwise	0.12 (0.32)	0.14 (0.35)	0.12 (0.32)	0.02
Biological pest control	1 if a farmer adopted biological pest control practices (e.g. biopesticides) in rice production, 0 otherwise	0.09 (0.29)	0.21 (0.41)	0.08 (0.28)	0.13***
Pesticide use	Expenditures on chemical pesticides (yuan/mu)[a]	77.76 (87.59)	75.44 (75.58)	78.02 (88.90)	−2.58
Rice yield	(100 kg/mu)	5.30 (1.77)	5.01 (1.73)	5.33 (1.77)	−0.32
Treatment variable					
Cooperative membership	1 if a farmer has membership in an agricultural cooperative mainly providing production services, 0 otherwise	0.10 (0.30)			
Independent variables					
Age	Age of household head (years)	54.11 (12.48)	51.16 (10.36)	54.44 (12.66)	−3.28
Gender	1 if household head is male, 0 otherwise	0.65 (0.48)	0.70 (0.46)	0.64 (0.48)	0.06
Education	Educational level of household head (years)	6.89 (3.93)	6.91 (4.09)	6.89 (3.92)	0.02
Health	Self-rated health status of household head: 1 = very unhealthy, 2 = unhealthy, 3 = well, 4 = healthy and 5 = very healthy	3.97 (0.98)	4.00 (1.00)	3.97 (0.98)	0.03
Household size	Number of members in a household (persons)	4.48 (1.55)	4.67 (1.57)	4.46 (1.55)	0.22
Off-farm worker ratio	Ratio of off-farm workers to household size	0.37 (0.25)	0.33 (0.24)	0.37 (0.25)	−0.05
Child ratio	Ratio of child (≤15 years old) to household size	0.16 (0.19)	0.18 (0.18)	0.16 (0.19)	0.02
Farm size	Total farm size for rice production (mu)	8.16 (27.24)	17.69 (47.77)	7.11 (23.79)	10.58**

TABLE 1 (Continued)

Variable	Definitions	Overall ($n = 432$) Mean (SD)	Members ($n = 43$) Mean (SD)	Nonmembers ($n = 389$) Mean (SD)	Mean difference
Insect experience	1 if a farmer experienced rice production loss caused by insects (e.g. aphids, rice planthopper, or Cnaphalocrocis medinalis), 0 otherwise	0.11 (0.32)	0.09 (0.29)	0.12 (0.32)	−0.02
Asset ownership	1 if a farmer owns a microwave oven, 0 otherwise	0.25 (0.43)	0.21 (0.41)	0.25 (0.44)	−0.05
Distance to input market	Distance to the nearest input market (km)	3.96 (3.21)	4.06 (1.67)	3.94 (3.34)	0.12
Road condition	1 if the road to the nearest transportation is good, 0 otherwise	0.67 (0.47)	0.63 (0.49)	0.67 (0.47)	−0.05
Jiangsu	1 if a farmer is from Jiangsu province, 0 otherwise	0.14 (0.35)	0.07 (0.26)	0.15 (0.36)	−0.08
Henan	1 if a farmer is from Henan province, 0 otherwise	0.14 (0.35)	0.28 (0.45)	0.13 (0.34)	0.15***
Hubei	1 if a farmer is from Hubei province, 0 otherwise	0.18 (0.39)	0.16 (0.37)	0.18 (0.39)	−0.02
Hunan	1 if a farmer is from Hunan province, 0 otherwise	0.27 (0.44)	0.28 (0.45)	0.27 (0.44)	0.01
Sichuan	1 if a farmer is from Sichuan province, 0 otherwise	0.26 (0.44)	0.21 (0.41)	0.27 (0.44)	−0.06
Peer membership (IV)	1 if a farmer's relatives or friends have cooperative membership, 0 otherwise	0.22 (0.41)	0.84 (0.37)	0.15 (0.36)	0.69***

Abbreviation: SD, standard deviation.

*** $p < 0.01$ and ** $p < 0.05$.

[a] Yuan is a Chinese currency, with 1 USD = 6.61 Yuan in May 2022; 1 mu = 1/15 hectare.

4 | RESULTS AND DISCUSSION

4.1 | Results of the ESP model estimates

In this section, we discuss the results of the ESP model estimations. In the lower parts of Table 2, we report the estimates of the selectivity correction terms. The statistically significant and positive coefficient of ρ_1 in Table 2 confirms the presence of selection bias originating from unobserved heterogeneities. A failure to account for this bias would lead to biased estimates. Furthermore, the Wald χ^2 test is statistically significant for estimations on physical pest control practices, suggesting that the null hypothesis that cooperative membership is exogenous in the physical pest control practice adoption equation should be rejected. These findings confirm that the ESP model is appropriate for estimating the relationship between cooperative membership and the adoption of physical pest control practices. In contrast, the Wald χ^2 test for estimations on biological pest control practices is not statistically significant, implying that cooperative membership is exogenous in the adoption of biological pest control model specification. Therefore, in principle, an ordinary probit model could estimate the factors that influence the adoption of biological pest control practices. Nevertheless, because the ESP model estimates three equations and provides more information, we use the results for estimations of biological pest control practices for interpretations (columns 5–7 of Table 2).

4.1.1 | Determinants of cooperative membership

The estimates for the factors influencing a farmer's decision to join an agricultural cooperative are presented in columns 2 and 5 of Table 2, which are estimated by the selection equation (2). Given these results can be interpreted as normal probit coefficients, we discuss them together. In both specifications, the coefficients of the age variable are negative and statistically significant, suggesting that older farmers are less likely to be cooperative members. Older farmers may have unfavourable working capabilities, restricting their ability to participate in activities (e.g. workshops and field training) organised by agricultural cooperatives. The negative impact of age on cooperative membership was also reported by Yu et al. (2021). The negative and statistically significant coefficients of the education variable imply that better-educated household heads have a significantly lower likelihood of becoming cooperative members. This finding disagrees with some previous studies (Ito et al., 2012; Mojo et al., 2017). However, our finding is consistent with that of Li, Cheng, and Shi (2021). Better education may empower rural farmers to participate in off-farm work activities that are usually more rewarding, reducing their motivation to participate in farm activities, including membership in agricultural cooperatives.

The coefficients of the farm size variable are positive and statistically significant, suggesting that farmers cultivating larger parcels of land are more likely to join cooperatives. Our finding is consistent with the result of Mojo et al. (2017). Professional guidance from agricultural cooperatives facilitates households with larger farm sizes to achieve economies of scale, motivating them to have membership in cooperatives. The asset ownership variable exerts a negative and significant impact on cooperative membership, which aligns with Ma et al. (2022). Microwave oven ownership is a proxy of household wealth. Wealthier farmers have enough resources (e.g. financial capital for buying yield-increasing inputs such as pesticides and labour) to improve farm production rather than relying on cooperatives' services, which may reduce their enthusiasm for joining a cooperative.

The results reveal a negative and statistically significant relationship between road conditions and cooperative membership, indicating that good road conditions are associated with a lower propensity to join agricultural cooperatives. Good road conditions reduce transaction

TABLE 2 Determinants of cooperative membership and farmers' adoption of physical and biological pest control practices: ESP model estimates.

		Physical pest control practices			Biological pest control practices	
Variables	**Selection**	**Members**	**Nonmembers**	**Selection**	**Members**	**Nonmembers**
Age	−0.022 (0.011)**	−0.312 (0.022)***	−0.004 (0.010)	−0.023 (0.011)**	0.058 (0.068)	0.005 (0.008)
Gender	0.007 (0.232)	0.964 (0.587)	0.019 (0.199)	0.062 (0.230)	−0.757 (0.922)	−0.006 (0.218)
Education	−0.065 (0.037)*	−0.221 (0.066)***	0.007 (0.031)	−0.074 (0.039)*	0.225 (0.154)	0.045 (0.031)
Health	0.168 (0.123)	3.625 (0.219)***	0.023 (0.089)	0.161 (0.130)	0.213 (0.340)	0.126 (0.125)
Household size	0.056 (0.105)	1.050 (0.107)***	0.002 (0.070)	0.034 (0.102)	0.215 (0.162)	0.058 (0.074)
Off-farm worker ratio	−0.699 (0.530)	2.335 (0.643)***	0.283 (0.393)	−0.510 (0.502)	−2.082 (1.171)*	−0.268 (0.414)
Child ratio	−0.426 (0.616)	6.432 (0.954)***	0.967 (0.482)**	−0.457 (0.630)	−4.864 (3.194)	−0.882 (0.806)
Farm size	0.005 (0.003)*	0.043 (0.003)***	0.007 (0.003)**	0.006 (0.003)**	−0.014 (0.008)*	0.004 (0.004)
Insect experience	−0.182 (0.347)	0.007 (0.237)	0.028 (0.288)	−0.116 (0.321)	−7.328 (1.565)***	0.571 (0.258)**
Asset ownership	0.447 (0.261)*	1.145 (0.297)***	0.007 (0.207)	0.363 (0.263)	1.662 (0.772)**	0.043 (0.245)
Distance to input market	−0.012 (0.028)	1.669 (0.109)***	−0.098 (0.031)***	−0.006 (0.026)	−0.016 (0.200)	−0.068 (0.035)**
Road condition	−0.523 (0.239)**	5.548 (0.456)***	−0.412 (0.194)**	−0.538 (0.245)**	0.210 (0.727)	−0.068 (0.227)
Jiangsu	−0.948 (0.458)**	−3.481 (0.287)***	−0.467 (0.359)	−0.964 (0.475)**	−8.653 (2.704)***	−0.954 (0.573)*
Henan	−0.171 (0.332)	−23.461 (1.141)***	−0.230 (0.436)	−0.177 (0.319)	1.898 (1.675)	−0.202 (0.393)
Hubei	0.009 (0.350)	−6.895 (1.252)***	0.312 (0.334)	−0.124 (0.353)	−6.517 (2.202)***	−0.510 (0.345)
Hunan	0.284 (0.333)	5.575 (0.516)***	1.158 (0.278)***	0.252 (0.339)	0.688 (0.823)	0.273 (0.258)
Constant	−0.979 (0.897)	−21.757 (2.321)***	−1.395 (0.729)*	−0.793 (0.961)	−5.503 (4.358)	−2.228 (0.829)***
Peer membership (IV)	2.223 (0.244)***			2.185 (0.245)***		
ρ_1		0.999 (0.000)***			−0.574 (0.406)	
ρ_0			−0.999 (0.002)			0.256 (0.475)
Wald test	$\chi^2(2) = 62{,}711.40$; Prob > $\chi^2 = 0.000$			$\chi^2(2) = 1.46$; Prob > $\chi^2 = 0.482$		
Sample size		432			432	

Note: Robust standard errors are presented in parentheses; *** $p < 0.01$, ** $p < 0.05$ and * $p < 0.10$; The reference province is Sichuan.

costs and improve farmers' access to input and output markets (Charlery et al., 2016; van de Walle, 2009), reducing farmers' dependence on the collective action of cooperatives. Farmers in Jiangsu province are significantly less likely to be cooperative members than those in Sichuan province. Finally, our instrumental variable used for model identification has a statistically significant and positive effect on cooperative membership, suggesting that farmers with relatives and friends who are members of cooperatives are more likely to have cooperative membership.

4.1.2 | Determinants of adopting physical pest control practices

Generally, the factors influencing physical pest control practices differ conspicuously between cooperative members and nonmembers (see columns 3 and 4 of Table 2). For example, among cooperative member groups, the probability of adopting physical pest control practices is significantly and positively associated with younger farmers' age, a lower education level, better health conditions of household heads, larger households, higher off-farm work ratios and microwave oven ownership. But these variables do not exert significant effects on nonmembers' adoption of physical pest control practices.

The negative relationship between the household head's age and the adoption of physical pest control practices can be explained by the diminishing working ability, which is consistent with the findings of Tang and Luo (2021). The coefficient of household size is positive and statistically significant for cooperative members, suggesting that larger households are associated with a higher probability of adopting physical pest control practices. Physical pest control practices need additional capital and labour inputs—for example, the application and maintenance of mechanical equipment. A larger household size provides an adequate labour force for applying physical pest control practices. The findings are similar to the results of previous studies (Carrión Yaguana et al., 2016; Tang & Luo, 2021). The positive and significant impact of the off-farm worker ratio on physical pest control practices can be explained by the income-increasing effects of off-farm work participation, which is necessary to invest in physical pest control practices.

The child ratio variable's positive and statistically significant coefficient suggests that households, whether cooperative members or nonmembers, with more children, are more likely to adopt physical pest control practices. Since rice production is an essential source of household diet, farmers may prefer physical pest control practices over chemical pesticides to reduce the pesticide residue of rice, which benefits the nutrition requirements of household members, especially children. The farm size variable shows positive and significant effects on the probabilities of adopting physical pest control practices for both cooperative members and nonmembers. This finding suggests that having a larger area of land under rice cultivation increases the chances of rice farmers using physical pest control measures. This is consistent with other empirical studies on the effect of cooperative membership on adopting green pest management practices (Zhang et al., 2023; Zhang & Yu, 2021). Larger farms may enable members to benefit more from physical pest management practices, contributing to an increased likelihood of adopting them. The asset ownership variable exerts a positive and statistically significant impact on the adoption of physical pest control practices, indicating that wealthier cooperative members are more likely to invest in physical pest control practices (Liu et al., 2022).

Column 3 of Table 2 shows that the distance from the household to the input market increases the likelihood for cooperative members to adopt physical pest control practices and reduces the probability of nonmembers, on the other hand. This implies that for farmers in cooperatives, living far away from input markets increases their likelihood of using pest-killing lamps and sticky plate traps, while nonmembers are less likely to use these means of pest control. For the indicators of geographic location, rice farmers located in the Jiangsu, Henan and

Hubei provinces, who have cooperative membership, are less likely to adopt physical pest control practices than those located in Sichuan province. Conversely, both cooperative members and nonmembers in Hunan province are more likely to adopt physical pest control practices than those located in Sichuan province.

4.1.3 | Determinants of adopting biological pest control practices

The results reporting the factors that affect rice farmers' decisions to adopt biological pest control practices for cooperative members and nonmembers are presented in the last two columns of Table 2. The coefficient of the off-farm worker ratio variable is negative and statistically significant in the third column, suggesting that having more off-farm workers in the household reduce the likelihood of adopting biological pest control practices among cooperative members. These findings are supported by Gao et al. (2019), who found that the number of household members capable of working decreases the likelihood of family farms' adoption of green control techniques. The farm size variable has a significant and negative coefficient in the third column. The findings indicate that households with larger land sizes are less likely to adopt biological pest control practices. Relative to chemical pesticides, biopesticides are less effective in managing pests. Thus, large-scale farmers may be less likely to adopt biological pest control practices to ensure the gains from farm production. Experiencing output loss due to insect infestation reduces the probability of cooperative members using biological pest control practices. Cooperatives may provide services on collective pest control when their members experience pest attacks to reduce production loss and sustain agricultural productivity. Thus, cooperative members may prefer to apply chemical pesticides rather than biological pesticides (Ma & Zheng, 2022).

The coefficient on the asset ownership variable for cooperative members is positive and statistically significant, suggesting that rice farmers in cooperatives that own at least a microwave are more likely to use biological pest control techniques. Wealthier households are more likely to afford expensive biological pesticides. The findings are in line with Tang and Luo (2021). It shows a negative and statistically significant impact of the distance from households to the input market on the likelihood of nonmembers adopting biological pest control practices. This could be due to the subsequent difficulty in accessing biopesticides. This association is insignificant for cooperative members. Concerning the geographic location indicators, cooperative members and nonmembers in the Jiangsu province are less likely to adopt biological pest control practices than those in the Sichuan province. Also, being in the Hubei province reduces the likelihood of cooperative members adopting biological pest control measures compared to those in the Sichuan province.

4.1.4 | Treatment effects of cooperative membership

The treatment effects of cooperative membership are presented in Table 3. The ATE are calculated based on the coefficients presented in Table 2 and Equation (7). The table shows that the average effects of cooperative membership are to significantly increase the probabilities of adopting physical and biological pest control practices by 6% and 19%, respectively. This finding is similar to that of Li, Cheng, and Shi (2021) and Yu et al. (2021), who found that Chinese farmers participating in cooperatives are more likely to implement integrated pest management measures and green control technologies. Overall, a positive association between cooperative membership and green pest control practices in rice cultivation highlights that agricultural cooperatives are an important catalyst that encourages smallholder farmers' adoption of environmentally friendly and nontoxic practices for controlling pests.

TABLE 3 Average treatment effects of cooperative membership on the adoption of green pest control practices.

	Mean outcomes			
Outcome	**Actual**	**Counterfactual**	**Treatment effects**	***t*-value**
Physical pest control	0.12 (0.32)	0.06 (0.48)	0.06 (0.35)***	3.34
Biological pest control	0.09 (0.29)	−0.09 (0.44)	0.19 (0.35)***	11.20

Note: Standard errors are presented in parenthesis. ***$p < 0.01$.

4.2 | Results of mediation analysis

Adoption of green pest control practices may mediate the effects of cooperative membership on chemical pesticide expenditures. As discussed in Section 2.2.4, we conduct a mediation analysis using the adoption of physical pest control practices and biological pest control practices as two mediating variables. The results are presented in Table 4. We find that the direct effects of cooperative membership on chemical pesticide expenditures are insignificant, a finding that is consistent with Ma et al. (2018). The 95% confidence intervals of coefficients representing total indirect effects range from −13.908 to 0.429 in percentile (P) confidence interval estimation and from −14.434 to 0.149 in bias-corrected (BC) confidence interval estimation, indicating that the total indirect effects are also insignificant. We go one step further to compare the indirect effects of physical and biological pest control practices. It shows that the coefficient of physical pest control is −0.086, which is statistically insignificant. In comparison, the coefficient representing the indirect effect of the adoption of biological pest control is −5.598, which is statistically significant at the 1% level. The finding suggests that cooperative membership significantly reduces chemical pesticide expenditures by improving the probability of adopting biological pest control practices rather than improving the likelihood of adopting physical pest control practices. The findings underscore the necessity of distinguishing the physical and biological pest control practices. As indicated earlier, previous studies failed to consider this (Li, Cheng, & Shi, 2021; Liu et al., 2022; Yu et al., 2021).

4.3 | Relationship between adoption of physical and biological pest control practices

Physical pest control practices and biological pest control practices play a similar role in pest management. Do rice farmers choose to adopt one to substitute or complement another? To answer this, we explore the interactive relationships between the adoption of physical and biological pest control practices. Because the treatment and outcome variables are binary variables, we employ the ESP model to first estimate the impact of the adoption of physical pest control practices on the adoption of biological pest control practices and then to estimate the impact of the adoption of biological pest control practices on the adoption of physical pest control practices. Table S2 in the Appendix presents the empirical results. It shows that the adoption of physical pest control practices increases the probability of adopting biological pest control practices by 34%, and the adoption of biological pest control practices increases the probability of adopting physical pest control practices by 31%. The findings reveal a complementary relationship between the adoption of physical pest control practices and the adoption of biological pest control practices. In other words, farmers are adopting the two practices simultaneously to manage pests effectively.

TABLE 4 Mediation effects of adopting green pest control practices on chemical pesticide expenditures.

Mediators	Coefficient	Bootstrapped SE	95% confidence intervals		
			Lower	Upper	
Direct effects	7.321	12.775	−16.076	33.999	(P)
			−18.183	32.076	(BC)
Total indirect effects	−5.684	3.695	−13.908	0.429	(P)
			−14.434	0.149	(BC)
Physical pest control	−0.086	1.123	−2.754	1.972	(P)
			−3.430	1.601	(BC)
Biological pest control	−5.598***	3.316	−13.252	−0.212	(P)
			−14.076	−0.673	(BC)
Total effects	1.637				

Note: (P) refers to the percentile confidence interval, and (BC) refers to the bias-corrected confidence interval. ***$p < 0.01$.

4.4 | Impact of adoption of green pest control practices on rice yield

The analysis in Section 4.2 reveals that cooperative membership reduces chemical pesticide expenditures by improving the adoption of green pest control practices, particularly biological pest control. Here, we further investigate how the adoption of green pest control practices affects rice yield. Because the ESP model requires a binary outcome variable while the rice yield is a continuous variable (Lokshin & Sajaia, 2011), we employ endogenous switching regression (ESR) to do the empirical analysis (Lokshin & Sajaia, 2004). The ESR model is more appropriate when estimating the impact of a binary treatment variable on a continuous variable. For the sake of brevity, we do not report the results that investigate the determinants of cooperative membership and determinants of rice yield for cooperative members and nonmembers. We only report the ATTs that illustrate the treatment effects of adopting physical and biological pest control practices on rice yield. The results (Table 5) show that adopting physical pest control practices significantly increases rice yield, while the adoption of biological pest control practices has a positive but insignificant impact on rice yield. Interestingly, our estimates provide evidence that the adoption of environmentally friendly practices that promote sustainable farm production could sustain or even increase crop yield.

5 | CONCLUSIONS AND POLICY IMPLICATIONS

Agricultural cooperatives play an increasingly crucial role in increasing farm performance, improving rural household welfare and boosting rural development. This study contributes to the literature by exploring whether cooperative membership can increase the adoption of green pest control practices, utilising data collected from rice farmers in China. The ESP model was employed to address the selection bias issue, acknowledging that farmers self-select themselves into cooperative members and nonmembers. We also explored the potential mediating role of green pest control practices in reducing pesticide use, the relationship between physical and biological pest control practices, and how the adoption of these green pest control practices affects rice yield.

The results showed that cooperative membership increases the probabilities of adopting physical pest control practices and biological pest control practices by 6% and 19%, respectively. Besides, we found that the age and education of household heads, farm size and road conditions determine farmers' decisions to have cooperative membership. Farmers' decisions

TABLE 5 Treatment effects of green pest control practices on rice yield: endogenous switching regression estimates.

Outcome	Treatment	Mean outcomes		ATT	*t*-value
		Actual	Counterfactual		
Rice yield	Physical pest control	5.69 (1.70)	4.87 (0.53)	0.82 (1.74)***	3.31
	Biological pest control	5.53 (1.99)	5.31 (0.37)	0.22 (1.88)	0.74

Note: Robust standard errors are presented in parenthesis. ***$p < 0.01$.

Abbreviation: ATT, average treatment effects on the treated.

to adopt green pest control practices were influenced by factors such as child ratio, farm size, distance to input markets and road conditions. The mediation analysis revealed that cooperative membership does not significantly and directly reduce pesticide expenditures. However, cooperative membership significantly reduces pesticide expenditures by increasing the adoption of biological pest control practices. When managing pests, farmers adopted physical and biological pest control practices complementarily rather than substituting them. Further analysis showed that the adoption of physical pest control practices significantly increases rice yield, but the adoption of biological pest control practices does not.

This study's findings have crucial policy implications for promoting the adoption of green pest control practices in China and other countries that also promote environmentally friendly farming practices. The discovery of the positive association between cooperative membership and the adoption of green pest control practices suggests that government should further encourage smallholder farmers to join agricultural cooperatives and help them benefit from the collective action. Our survey reveals that the rate of adopting green pest control practices remains quite low among farmers. The government should help increase farmers' awareness of and benefits of adopting those environmentally friendly practices through workshops organized by agricultural cooperatives and improve their knowledge and understanding of the benefits of substituting chemical pesticides with green pest control practices. Farm size is positively associated with the adoption of physical pest control practices. Thus, there is a need to target and help farmers cultivate larger farms to adopt physical pest control practices, motivating other farmers' intentions to uptake the practices.

In the present study, rice farmers' decisions to adopt physical and biological pest control practices were captured by two dichotomous variables. Agricultural cooperative membership might affect the areas of land allocated to adopt physical and biological pest control practices. However, the lack of relevant data limits our capability to explore it. Nevertheless, we believe that investigating the potential heterogeneous effects of cooperative membership across farmers who adopted the two practices on different land sizes and plots would be an interesting area to be explored in the future.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from Hongyun Zheng upon request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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