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RESEARCH ARTICLE

Estimating effects of cooperative membership on farmers' safe production behaviors: evidence from the rice sector in China

Houjian Li[1] · Yu Liu[1] · Xuemei Zhao[1] · Lichen Zhang[2] · Kaihua Yuan[3]

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Abstract

The current agricultural system in China highly depends on chemical fertilizers and pesticides. Consequently, agricultural production activities cause various environmental issues. Carrying out safe production provides vital support for sustainable development of agriculture, which may improve this situation. The past decades have witnessed the fast development of rural cooperatives organization in China. Given the fact that rural cooperative organization plays a crucial role in agricultural production, however, there is little empirical evidence on the relationship between cooperative membership and safe production of smallholders in China. This study aims to investigate whether the participation in farmer cooperatives contributes to safe production in agriculture in China. Using survey data covering 623 rice-producing farm households in Sichuan province in China, this study employs the endogenous switching regression model to examine the effects of the participation in farmer cooperatives on safe production in rice agriculture. The results show that cooperative membership has significantly positive effects on safe production in rice agriculture. In particular, the average treatment effects demonstrate that without the participation in cooperatives, the members' adoption of the green control techniques would reduce by 74.491%, the application of artificial weeding would reduce by 38.768%, and organic fertilizer input would reduce by 23.448%. Furthermore, the marginal treatment effect is employed to evaluate the heterogeneous effects of the participation in farmer cooperatives on safe production in rice agriculture. Heterogeneous effect analyses suggest that farmers who are more likely to participate in farmer cooperatives are easier to adopt green control technology, while farmers who are less likely to participate in farmer cooperatives are easier to adopt artificial weeding and increase organic fertilizer input. To improve safe production in rice agriculture, the Chinese government is expected to encourage rice farmers to participate in rural cooperative organizations, and to stimulate rice farmers to take collective action to address environment issues arising from agricultural production.

Keywords Cooperative membership · Safe production behaviors · Rice farmers · Adoption of the green control techniques · Artificial weeding · Organic fertilizer input · Collective action

Introduction

Rice is the world's most important food crop, and it has always been relevant to global food security and socio-economic stability (Zeigler and Barclay 2008). Rice production is deeply rooted in the socio-political culture of Asia (Bouman et al. 2007). In particular, rice has been a significant icon of Chinese culture for thousands of years (Hung 2016).

However, imbalanced and excessive fertilization has caused a series of environmental problems and threatened food security in China (Xu et al. 2014). Overuse of fertilizer in rice production is a major source of pollutants found in the air, waters, soil, and rice products (Chapagain and Hoekstra 2011; Lin et al. 2014), thus leading to undesirable adverse

Yu Liu is the co-first author.

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✉ Kaihua Yuan
casparyuan@126.com

[1] College of Economics, Sichuan Agricultural University, Wenjiang District, Chengdu 611130, Sichuan Province, China

[2] School of Public Affairs, Chongqing University, Shapingba District, Chongqing 400044, China

[3] College of Economics, Zhongnan University of Economics and Law, Wuhan 430074, Hubei Province, China

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impacts on human health and the environment (Bolan et al. 2013; Wang and Lu 2020). Concerns on human health and environment issues mainly arise from the excessive application of fertilizer and pesticides in agricultural production. These concerns contributed to China's prioritization of environment protection in a recent policy statement as well as the implementation of environmentally friendly agricultural practices to assure food safety and security (Liu et al. 2020). Food safety is an issue of growing importance for China as well. According to the definition of food safety of the World Health Organization, food shall be nontoxic and harmless, conform to proper nutritive requirements.

Safe production is an important part of the comprehensive food safety strategies (Stecchini and Del Torre 2005). Farmers' safe production behaviors mainly refer to using green control techniques instead of chemicals to reduce the diseases of insect pests. Specifically, green technologies are production technologies that save exhaustible resources and emit less greenhouse gases (Rodrik 2015). Previous research about safe production are mostly focusing on high value-added products, such as peanuts (Chang et al. 2013), oilseed rape (Yu et al. 2014), spinach (Karp et al. 2015), tomatoes (Dyk et al. 2016), lettuce (Tozzi et al. 2019), citrus (Panghal et al. 2018), pork (Unnevehr et al. 1999; Ji et al. 2019), beef (Ruegg 2003), chicken (Young et al. 2010) and aquaculture (Broughton and Walker 2010). In recent years, people have realized that rice is an important food crop (Mannan et al. 2017), so research on the safe production of rice has also increased (Kim et al. 2014; Qiu et al. 2011; Xiao et al. 2018). In addition to ensuring food safety, the safe production of rice can reduce the greenhouse-gas intensity in the atmosphere (Van Groenigen et al. 2012) and enhance the sustainable use of agricultural resources (Bhullar 2015).

However, rice production is decentralized in China, which makes it difficult to promote the safe production of rice. China's agricultural sector is a system based on smallholder production (Scott et al. 2014; Wan and Yang 2016). It is difficult to popularize the safe production mode because the main body of production is scattered, the scale is small and the smallholders' quality is not high. Moreover, rational smallholders seek to maximize their own interests while avoiding risks (Newton 1977; Adams 1986; Weirich 2004). In the situation of asymmetric information of agricultural product quality, poor source traceability, and imperfect governance system, most small farmers in China lack sufficient internal incentives to participate in agricultural safety production (Jiang et al. 2013). If the safe food products provided by smallholder farmers cannot be recognized by the market, rational smallholders under the market risks and natural disaster risks would choose to invest more pesticides and fertilizers instead of safe production. Because the cost of using chemicals is lower than that of safe production, and they can increase rice yield. At the same time, safe production technology is a knowledge-intensive technology, but the educated level of most Chinese farmers is not high. Therefore, if farmers are to be promoted to participate in safe production, they need systematic training. For this purpose, safe production of rice is more complicated in China.

Collective action through farmer groups can be an important strategy for smallholders to remain competitive in the rapidly changing markets (Fischer and Qaim 2012).In order for green products to be recognized by consumers, producers must join a green organization (Walter and Chang 2017). In many developing countries, rural cooperatives are the main vehicle for promoting the adoption of agricultural techniques and small-scale production (Ma 2016). Thus, farmers recently have become aware of the importance of adopting innovations through collective action (Nwankwo et al. 2009), which can help farmers to achieve safe production.[1] Collective actions play important roles in the delivery of various public agricultural services, such as dissemination of agricultural inputs, collection and sale of members' outputs, provision of business loans, and offering training to members (Spielman et al. 2010). Collective actions of peasant workers are characterized by mutual-benefit coordination mechanisms aimed at the fulfillment of members' participation rights and welfare (Sacchetti and Tortia 2013). Membership characteristics include the access to labor, land tenure, risk aversion, and mutual trust between farmers and cooperatives' management (Mujawamariya et al. 2013). Paxton and Young (2011) also noted that cooperative member households were socially and economically more dynamic than non-member households. Cooperative membership increases farmers' income and reduces poverty in general (Verhofstadt and Maertens 2015). More importantly, studies indicated that cooperatives could help accelerate the adoption of agricultural technologies by smallholder farmers (Abebaw and Haile 2013). In other words, cooperative membership has a positive and significant effect on technology adoption and household welfare (Wossen et al. 2017).

However, the existing literature studied the economic returns (Hoken and Su 2018; Motamed 2010) and agricultural production efficiency (Milovanovic and Smutka 2018) of cooperative membership on rice production, but little research is about the effects on rice production safety. This study aims to contribute to knowledge about whether a farmer participating in a cooperative contributes to rice safe production in China and discuss the policy implications for safe production. Using cross-sectional survey data, this paper first measures the rice safe production and employs endogenous switching

[1] There were 2.17 million farmer cooperatives registered with industrial and commercial authorities in China by the end of 2018.(Data source: National Bureau of Statistics of China)

regression to rigorously analyze the impact of cooperatives on safe production. The findings in this paper reveal that rice farmers through the participation in farmer cooperatives can achieve rice safe production in China. For the purpose of safe production, several policy implications are discussed and proposed.

Literature review

Most farms in China are small and vulnerable to the influence of powerful market forces (Deng et al. 2010), which could bring various problems to agricultural production, such as imperfect markets, high transaction costs, and poor infrastructure. Many studies have shown that small farmers can overcome these restrictions if they are organized into collective action groups, such as cooperatives (Markelova et al. 2009; Mojo et al. 2017; Narrod et al. 2009; Poulton et al. 2004). Cooperatives are generally considered to play an important social and economic role among their members by reducing transaction costs and improving individual bargaining power in all sectors including agriculture (Staatz 1987).

A vast scope of studies has shown that agricultural cooperatives are important to agricultural innovation and information delivery in China. Agricultural cooperatives link the technical, social, and economic aspects of agricultural practice, provide corresponding services, and increase members' contact with new technologies. Meanwhile, agricultural cooperatives help farmers to absorb the accumulated experience of other members into the experiments. As a result, agricultural cooperatives improve the effectiveness and efficiency of the agricultural technology system in turn. Cooperatives know their members' needs very well and have direct contact with them, which enable cooperatives to be used as a channel for horizontal learning and information sharing among different member groups (Blandon et al. 2009; Roy and Thorat 2008). They will stand on the interface among highly dispersed members, overly concentrated technology generation, and dissemination institutions (Carney 1996), play the role of coordinator in the service system, and bridge the gap between the policy system and daily agricultural practice (Kilelu et al. 2011).

However, not everyone is optimistic about the role of agricultural cooperatives (Markelova et al. 2009). It is widely accepted that cooperative memberships have positive impacts on price, output, input options, income, and other performance indicators of members. However, more and more evidence shows that due to potential conflicts with the government, market actors, or their members, the interests of small producers and large producers are unevenly distributed (Grashuis and Su 2019; Xu et al. 2013). It is still difficult for many cooperatives to achieve their goal of being the vanguard of efficient processing, distribution, and supply procurement, and to obtain the highest net return of products or the lowest average cost of agricultural supply and services for their member customers (Girma et al. 2011; Bernard et al. 2008; DeLoach 1962; Fischer and Qaim 2012).

In general, the economic rationale for agricultural cooperative has been explained in twofold theoretical frameworks. One is about the collective action theory (Markelova and Mwangi 2010). Collective action allows organizations to acquire resources and use them for member services, public relations, and political action (Stinchcombe 1990), helping members reduce production costs and increase profits. More importantly, participation in collective action feeds back to affect the individual's attitude and social identity (Kelly 1993). Findings suggested that more mature groups with strong internal institutions, functioning group activities, and a good asset base of natural capital were more likely to improve their market situation (Barham and Chitemi 2009; Zomeren and Iyer 2010).

The research found that the collective action mechanism was more plausible than the accountability mechanism in the context of rural China (Xu and Yao 2014). As a concrete manifestation of collective action, a farmer organization plays a crucial role in facilitating smallholders' access to input and output markets (Hellin et al. 2009). Noteworthy, most farmers actively participate in rural cooperatives in order to get access to information and social capital (Nwankwo et al. 2009). At present, the farmer cooperative is the largest[2] typical farmer organizations in China. Cooperatives can operate more efficiently than non-cooperative counterparts and reduce the aspects of the risk and uncertainty that plague farming (Sexton and Iskow 1988).

Another theory which is frequently used to explain the rationale of cooperatives is about transaction cost. The core contradiction between smallholders and large markets is transaction cost, which is pointed out to be the basis of the choice between the market and the hierarchy (Coase 1937). Collective action is driven by the incentive to save transaction costs (Kim 1999). Centralized trading of farmer cooperatives can help reduce the transaction cost of bargaining between individual smallholders and the large market, as well as the opportunism cost existing in the large market (Nazari and Keypour 2019). First, cooperatives help smallholders reduce the cost of safety certification (Yi et al. 2020). In China, Green Food certification is an important measure of food safety. The green food program was created by China's Ministry of Agriculture (MOA) in 1990. In 1992, the China Green Food Development Centre (CGFDC) was established under the auspices of the MOA to take responsibility for the national

[2] Learning from National Bureau of Statistics of China, by the end of 2018, China had 2.17 million farmers cooperatives, 600,000 family farms and 87,000 leading enterprises of agricultural industrialization.

development and management of green food. According to the regulations for green certification, agribusiness entities, which can be legal persons, farmers' cooperatives, family farms, state-owned farms, or regimental farms, are eligible to apply for green certification, although small farmers are not allowed to apply for it independently. Under this condition, cooperatives provide certification to farmers for safe production, which can solve the problem that the market cannot identify safe products produced by smallholders. Second, cooperatives help smallholders reduce the cost of collecting information (Verhofstadt and Maertens 2015). Cooperatives can collect all kinds of market information and help smallholders to complete the unified purchase of production materials, the unified production standards, and the unified sale of agricultural products in the process of safe production, thus reducing the number of transactions between smallholders and the market. Third, cooperatives help smallholders reduce the cost of technical training (Moustier et al. 2010). With advanced means of production and technology, farmer cooperatives can provide technical training on safe production to smallholders with a generally low educational level. In general, farmer cooperatives provide favorable conditions for smallholders' safe production. For this purpose, the specific effects of cooperative membership on farmers' safe production behaviors are studied in this paper.

Research methodology

Endogenous switching models

To reveal the effects of the rice cooperative membership on farmers' safe production behavior, it is necessary to measure the average treatment effect on the treated (ATT) of the safe production behavior of farmers who joined in rice cooperatives and the average treatment effect on the untreated (ATU) of the safe production behavior of farmers who did not join in rice cooperatives. However, some unobserved characteristics, such as farmers' personality trait, can lead to self-selection bias, which may affect both farmers' participation in rice cooperatives and farmers' safe production behaviors. Members and non-members cannot be directly compared due to potential self-selection bias, which means that an estimation method is needed to correct this bias. Through the endogenous switching regression (ESR) model, the estimates of the effects on farmers' safe production behavior can be obtained by using conditional expectations to calculate the potential outcome of the hypothesis. Thus, the self-selection bias is corrected. In addition, the ESP model is used in the paper to more accurately measure farmers' different safe production behavior. The principle of the endogenous switching probit (ESP) model is similar to that of the ESR model, except that the ESP model is for binary dependent variables and the ESR model is for continuous dependent variables.

The ESR model is divided into two stages.[3] In the first stage, a decision equation was established to analyze the factors influencing farmers' participation in rice cooperatives. The specific equation is as follows:

$$\mathrm{M}_i^* = Z_i\alpha + \mu_i \qquad M_i = \begin{cases} 1, & \text{if } M_i^* > 0 \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

M_i is the observed value of the behavior of farmers to participate in rice cooperatives for farmer i; $M = 1$ means participating in rice cooperatives, and $M = 0$ means not participating in rice cooperatives. Z_i represents the vector of factors influencing farmers' participation in rice cooperatives. α is the estimated coefficient of Z_i, and μ_i is a random error term.

In the second stage, it is needed to construct an outcome equation to analyze the influencing factors of farmers' safe production behavior. The specific equation is as follows:

$$\mathrm{Y}_{i0} = \beta_0 X_{i0} + \varepsilon_{i0} \quad \text{if } M = 0 \tag{2a}$$

$$\mathrm{Y}_{i1} = \beta_1 X_{i1} + \varepsilon_{i1} \quad \text{if } M = 1 \tag{2b}$$

where Y_{i0} and Y_{i1} are defined as the safe production behaviors of farmers who did not and who did participate in the rice cooperatives. X_{i0} and X_{i1} are the influence factor vectors of safe production behavior of farmers who did not and who did participate in rice cooperatives. β_0 and β_1 are regression coefficients, ε_{i0} and ε_{i1} are random error terms.

However, the safe production behaviors of farmer i cannot be measured in the cases of participating and not participating in the rice cooperative at the same time in reality. The safe production behaviors of farmer i depend on Eq. (1). If the ordinary least squares (OLS) method is directly estimated on Eq. (2), the problem of sample selection bias caused by observable and unobservable factors will occur, leading to the deviation of the estimated results. For this purpose, this paper gave full consideration to the possible factors influencing farmers' safe production behaviors and controls the sample selection bias caused by observable factors by reducing the missing variables. Besides, a covariance matrix Ω of the error terms of decision and outcome equations is constructed to correct the problem of sample selection bias caused by unobservable factors. As shown below:

$$\Omega = \begin{bmatrix} \sigma_\mu^2 & \sigma_{\mu1} & \sigma_{\mu0} \\ \sigma_{\mu1} & \sigma_1^2 & \cdot \\ \sigma_{\mu0} & \cdot & \sigma_0^2 \end{bmatrix} \tag{3}$$

In Eq. (3), σ_μ^2 =var (μ_i), σ_1^2 =var (ε_{i1}), σ_0^2 =var (ε_{i0}), $\sigma_{\mu1}$ = cov (μ_i,ε_{i1}), $\sigma_{\mu0}$ = cov (μ_i,ε_{i0}). Since the random disturbance

[3] The ESP model is similar to ESR model in mathematical analysis, so it is not listed in the text due to limited words.

term μ_i of the decision equation and the random error term $\varepsilon_{i0,}$ ε_{i1} of the outcome equation are related to each other, the conditional expectation i0 and i1 can be expressed as:

$$E(\varepsilon_{i1}|M=1)=\sigma_{\mu 1}\frac{\varphi(Z_i\alpha)}{\Phi(Z_i\alpha)}=\sigma_{\mu 1}\lambda_{i1} \tag{4}$$

$$E(\varepsilon_{i0}|M=0)=\sigma_{\mu 0}\frac{\varphi(Z_i\alpha)}{1-\Phi(Z_i\alpha)}=\sigma_{\mu 0}\lambda_{i0} \tag{5}$$

where φ and Φ respectively represent the standard normal probability density function and cumulative distribution function. $\lambda_{i1}=\frac{\varphi(Z_i\alpha)}{\Phi(Z_i\alpha)}$ and $\lambda_{i0}=\frac{\varphi(Z_i\alpha)}{1-\Phi(Z_i\alpha)}$ respectively represent the inverse Mills ratios of farmers who participated in rice cooperative and those who did not participate in rice cooperative, correcting the sample selection bias caused by unobservable factors. ε_{i0} and ε_{i1} are introduced into Eq. (2). After correcting the outcome equation, the new regression equations are as follows:

$$Y_{i0}=\beta_0X_{i0}+\sigma_{\mu 0}\lambda_{i0}+\omega_{i0} \quad \textit{if } M=0 \tag{6a}$$

$$Y_{i1}=\beta_1X_{i1}+\sigma_{\mu 1}\lambda_{i1}+\omega_{i1} \quad \textit{if } M=1 \tag{6b}$$

In Eq. (6), $\sigma_{\mu 0}\lambda_{i0}$ and $\sigma_{\mu 1}\lambda_{i1}$ are the sample selection deviation correction terms, and ω_{i0} and ω_{i1} are the random error terms. The other terms are the same as defined in Eq. (2). Additionally, sample selection bias caused by unobservable factors will appear if the covariance correlation coefficients ρ $\left(\frac{\sigma_{\mu 0}}{\sigma_\mu}\sigma_0\right)$ or ρ $\left(\frac{\sigma_{\mu 1}}{\sigma_\mu}\sigma_1\right)$ of the random error terms in the decision equation and the outcome equation are significantly non-zero.

For this purpose, under the framework of the ESR model, farmers' safe production behavior can be expressed as:

$$E(Y_{i1}|M=1;X)=\beta_1X_{i1}+\sigma_{\mu 1}\lambda_{i1} \tag{7a}$$

$$E(Y_{i0}|M=1;X)=\beta_0X_{i1}+\sigma_{\mu 0}\lambda_{i1} \tag{7b}$$

where (7a) represents the safe production behaviors of rice farmers who participated in cooperatives and the effects can be observed in actuality. Besides, (7b) represents the potentially safe production behaviors of rice farmers who have actually participated in cooperatives but assume that they have not participated in cooperatives. Since (7b) is unobservable in the actual situation and is inconsistent with the facts, it is defined as counterfactual. The average treatment effect of safe production behaviors of farmers who participated in rice cooperatives is the difference between (7a) and (7b) shown as follow:

$$\begin{aligned} \text{ATT}=(7\text{a})-(7\text{b}) &= \text{E}(Y_{i1}|M=1)-\text{E}(Y_{i0}|M=1) \\ &= \text{X}_{i1}(\beta_1-\beta_0)+\lambda_{i1}(\sigma_{\mu 1}-\sigma_{\mu 0}) \end{aligned} \tag{8}$$

Marginal treatment effects

The marginal treatment effects (MTE) is a choice-theoretic parameter that can be interpreted as a willingness to pay parameter for persons at a margin of indifference between participating in an activity or not (Vytlacil 2007). Due to the unobserved heterogeneity of the microcosmic survey data and the missing data caused by the condition contrary to the actual situation, the results obtained by OLS estimation are biased and inconsistent. The ESP and ESR models correct the selectivity bias caused by observable factors, but ignore the heterogeneous effects caused by unobservable factors, leading to the biased estimation results. The MTE approach developed by Heckman and Vytlacil (1999, 2005) suggests that people make decisions on whether to participate in an activity based on the principle of comparative advantage. Only when the benefits of participating in the activity outweigh the opportunity cost, will the individual be motivated to participate in the activity. The MTE method takes both observable and unobservable factors into account, solving the heterogeneous influence caused by unobservable factors. After the test of Stata command sktest, the sample data obeys a normal distribution. Thus the MTE method is applied in this section.

There are three methods to calculate the MTE, which are the local instrumental variable method (LIV), separation method, and maximum likelihood estimation (MLE) method. In this paper, the MLE method was selected to calculate the values of MTE. This method assumes that the random error terms of the decision equation and the outcome equation are normally distributed. Equations (1)and (2) above are integrated into the primary equation as follows:

$$Y_i=\beta X_i+\gamma M_i+\mu_i \tag{9}$$

Since M_i is a binary variable, the integration of Eq.(2) and Eq.(9) can be shown as the following equation.

$$Y_i=M_iY_{i1}+(1-M_i)Y_{i0}=\beta_iM_i+\beta_0X_i+\varepsilon_{i0} \tag{10}$$

$$\beta_i=(\beta_1-\beta_0)X_i+(\varepsilon_{i1}-\varepsilon_{i0}) \tag{11}$$

β_i is the heterogeneous effect of cooperative membership on farmer i's safe production behavior. If $\varepsilon_{i1}\neq\varepsilon_{i0}$, $(\varepsilon_{i1}-\varepsilon_{i0})$ is the unobservable heterogeneous effect.

The cooperative membership indicator is modeled as a nonlinear function of observables Z_i and unobservables v_i and is linked to the observed outcome Y_i through the latent variable M_i.

$$\begin{gathered} M_i^*=Z_i\alpha-v_i \qquad M_i=\begin{cases}1, & \textit{if } M_i^*>0\\ 0, & \textit{otherwise}\end{cases} \\ \text{Prob}(M_i=1|Z_i)=\Phi(Z_i\alpha) \\ \text{Prob}(M_i=0|Z_i)=1-\Phi(Z_i\alpha) \end{gathered} \tag{12}$$

Since the conditional independence assumption is not valid in the ESP and ESR models, ε_{i0}, ε_{i1} and v_i are allowed to

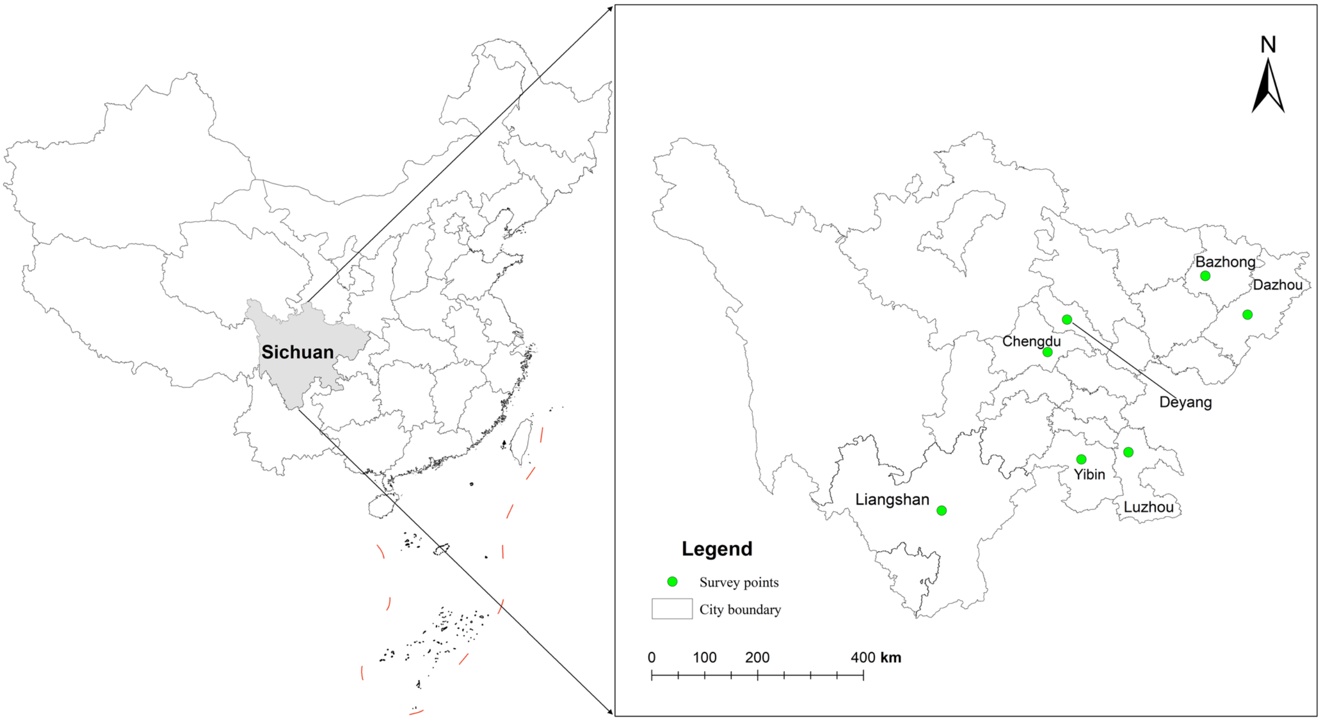

Fig. 1 The location of the sample distribution

correlate by the coefficient ρ and are assumed to be jointly normally distributed $(\varepsilon_{i0}, \varepsilon_{i1}, v_i) \sim N(0, \sigma^2)$. According to the relevant literature of MTE, it is usual to trace out the treatment effect against the percentiles of the distribution of v, in line with the following transformation of the selection rule in Eq.(12): $M_i^* > 0$ if $\Phi(Z_i\alpha) > \Phi(v_i)$. Since $\Phi(Z_i\alpha) = P_i(Z_i)$ represents the probability of rice farmer i participating in the cooperative, $\Phi(v_i) = UD$ denotes the percentiles of the distribution of the unobservable propensity of not participating in the cooperative. The condition $M_i^* > 0$ can then be

Table 1 Descriptive statistics of variables

Variable	All		Membership		Non-membership		Difference	*p* value
	Mean /percentage[a]	S. D.	Mean/ percentage	S. D.	Mean/ percentage	S. D.	(=(3)–(5))	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Green control techniques	0.658		0.933		0.355		0.578	0.000
Artificial weeding	0.181		0.275		0.078		0.198	0.000
Organic fertilizer	0.119	0.069	0.145	0.060	0.090	0.066	0.054	0.000
Gender	0.912		0.920		0.902		0.018	0.418
Age	56.93	10.31	57.673	8.891	56.108	11.640	1.565	0.058
Married	0.923		0.945		0.899		0.046	0.030
Siblings	3.342	1.602	3.572	1.486	3.088	1.687	0.484	0.000
Communication costs	6.303	0.531	6.364	0.396	6.235	0.643	0.128	0.003
Education	4.892	2.729	3.688	2.164	6.223	2.674	−2.535	0.000
Village cadre	0.059		0.064		0.054		0.010	0.593
Health	2.631		2.783		2.463		0.320	0.000
Household size	4.039	1.803	4.018	1.739	4.061	1.875	−0.042	0.769
Internet usage	0.798		0.798		0.797		0.001	0.979
Expert	1.900	0.597	1.927	0.400	1.872	0.757	0.055	0.251

[a] For categorical variables (green control techniques, artificial weeding, gender, married, village cadre, health, Internet use), column (1), column (3), and column (5) report the *percentage* rather than the *mean*.

rewritten as UD > v_i. The MTE can then be estimated as the partial derivative of the conditional expectation of Y with respect to the propensity score $P_i(Z_i)$, as follows:

$$\mathrm{MTE}(X_i = x, \mathrm{UD}_i = \rho) = \partial E\{Y_i | X_i = x, P_i(Z_i) = \rho\} / \partial\rho \quad (13)$$

It is thus the treatment effect for individuals with observed characteristics $X_i = x$ who are at the UD percentile of the v distribution, implying these individuals are indifferent between member and non-member when the propensity score $P_i(Z_i)$ equals UD.

Data description

Sample and data resources

The data used in this study is from rural household surveys of rice farmers conducted in August and September 2019. This study focused on Sichuan province, which regarded rice as its largest grain crop, with 30 million acres of planting areas and the total rice output about 15 million tons. The planting area and total output of rice respectively rank the 7th and 6th in China, which has the typical representative meaning. In the main rice production area in Sichuan province, seven prefecture-level cities or autonomous prefectures were selected randomly, including Chengdu, Bazhong, Dazhou, Yibin, Luzhou, Liangshan prefecture, as shown in Fig.1. From each prefecture-level city or autonomous prefecture, one or two counties (districts) with a high concentration of new business subjects were selected, and one or two townships (towns) were selected from each county. The survey targeted at small-scale rice farmers who were divided into two groups, cooperative members and non-members; and a two-step method of stratified random sampling was used to obtain the data.

In the first step, using the information provided by the Agricultural Department of the individual townships (towns), all the villages in each sample township (town) were divided into two categories: villages with new business entities and villages without new business entities. Next, according to the principle of stratified random sampling, one or two villages with new business entities were selected for each sample township (town). In order to make the selected villages with new business entities more comparable with the villages

Table 2 Effects of cooperative membership on farmers' GCT adoption

Variable	Decision equation	Outcome equation	
		GCT_1 (n=327)	GCT_0 (n=296)
Gender	0.149(0.253)	− 0.068(0.423)	0.216(0.310)
Age	0.177***(0.048)	0.012(0.089)	− 0.119*(0.063)
Age square	− 0.158***(0.040)	− 0.018(0.075)	0.078(0.055)
Married	0.482*(0.292)	0.075*(0.423)	− 0.109(0.303)
Siblings	− 0.012(0.044)	− 0.049(0.076)	0.054(0.052)
Communication costs	0.181(0.131)	0.057(0.315)	− 0.314**(0.129)
Education	− 0.310***(0.031)	− 0.054(0.075)	− 0.004(0.036)
Village cadre	1.061***(0.303)	0.397(0.534)	− 0.263(0.397)
Health	0.278***(0.101)	0.099(0.188)	− 0.007(0.113)
Household size	0.034(0.038)	− 0.062(0.064)	− 0.166***(0.049)
Internet usage	0.282*(0.165)	− 0.571(0.370)	− 0.200(0.217)
Expert	0.077(0.111)	0.142(0.297)	0.487***(0.118)
lntime	− 1.129***(0.099)		
Constant	− 3.353*(1.740)	0.847(3.591)	5.213***(1.950)
Athrho_1		0.335(0.398)	
Rhol_1		0.323(0.357)	
Arhrho_0			− 0.336*(0.189)
Rho_0			− 0.350*(0.165)
LR test of indep.eqns	4.65*		
Observations	623	623	623

The value of the variable "age square" is the age of the household head divided by 100. The bracketed values are standard errors

The p values are in parentheses. ***, **, and * indicate 1%, 5%, and 10% significance levels, respectively without new agribusiness entities, this paper selected one or two villages without new agribusiness entities which were similar to the villages with new agribusiness entities from the perspective of comprehensive evaluation results of the villages' economic conditions, traffic conditions, and rice potential productivity. The second step is to compile a complete list of all rice farmers in each sample village according to the data provided by the village committee. According to the list, this paper randomly selected about 10 rice farmers from each of the villages with new agribusiness entities and 10 rice farmers from the villages without new agribusiness entities.

The contents of the questionnaire included household head characteristics, family characteristics, rice planting inputs and outputs. Questionnaires were completed by trained graduate students and senior undergraduates, who conducted face-to-face household interviews. To determine the sample size, we followed the computational formula that the sample size $n = \frac{z^2 \times p(1-p)}{e^2}$, where z is the Z statistic at a certain confidence level (= 2.12), p is the estimated percentage in the population (= 20%), and e is the acceptable error (= 3.4%). Moreover, considering the incidence rate (99% in the previous survey) and response rate (98% in the previous survey), we adjusted the sample size. Finally, a total of 641 questionnaires were collected. After removing the samples with serious information deficiency or abnormality, the remaining valid questionnaires were 623.

Variable selection and measurement

Farmer's safe production behaviors

Food safety is an essential concern for humans. However, many issues surround the traceability of food products from the consumer through the marketing and processing firm and back to the farm of origin (Pouliot and Sumner 2008). At the source, the farmers' safe production behaviors directly determine the safety of food. According to authoritative books and literature, farmers' safe production behaviors from three aspects were studied that were adoption of green control techniques, artificial weeding, and organic fertilizer input. Green control technique (GCT) is a concept of Chinese integrated pest management. It prioritizes the adoption of resource-

Table 3 Effects of cooperative membership on farmers' artificial weeding

Variable	Decision equation	Outcome equation	
		Artificial weeding_1 (n=327)	Artificial weeding_0 (n=296)
Gender	0.109(0.256)	− 0.593**(0.284)	− 0.591*(0.336)
Age	0.176***(0.048)	− 0.221***(0.069)	− 0.024(0.078)
Age square	− 0.157***(0.040)	0.174***(0.058)	0.019(0.069)
Married	0.549*(0.296)	0.445(0.393)	0.091(0.388)
Siblings	− 0.002(0.044)	− 0.028(0.055)	0.002(0.076)
Communication costs	0.187(0.133)	0.181(0.212)	0.046(0.183)
Education	− 0.136***(0.031)	0.143***(0.045)	− 0.034(0.049)
Village cadre	1.009***(0.303)	0.417(0.317)	0.616(0.458)
Health	0.262***(0.100)	− 0.096(0.126)	− 0.109(0.162)
Household size	0.040(0.039)	− 0.042(0.048)	0.009(0.067)
Internet usage	0.277*(0.165)	− 0.890***(0.198)	0.126(0.351)
Expert	0.055(0.144)	0.003(0.199)	− 0.078(0.165)
lntime	− 1.147***(0.098)		
Constant	− 3.323*(1.743)	6.016**(2.639)	0.160(2.502)
Athrho_1		− 0.523*(0.286)	
Rhol_1		− 0.480*(0.220)	
Arhrho_0			0.610**(0.277)
Rho_0			0.544**(0.195)
LR test of indep.eqns	8.01**		
Observations	623	623	623

The value of the variable "age square" is the age of the household head divided by 100. The bracketed values are standard errors

The p values are in parentheses. ***, **, and * indicate 1%, 5%, and 10% significance levels, respectively

Table 4 Effects of cooperative membership on farmers' organic fertilizer input

Variable	Decision equation	Outcome equation	
		Organic fertilizer_1 (n=327)	Organic fertilizer _0 (n=296)
Gender	0.146(0.255)	0.018(0.012)	0.011(0.014)
Age	0.173***(0.048)	0.002(0.003)	− 0.003(0.003)
Age square	− 0.155***(0.040)	− 0.002(0.002)	0.002(0.003)
Married	0.508*(0.295)	0.018(0.014)	0.009(0.014)
Siblings	− 0.005(0.044)	− 0.007***(0.002)	0.002(0.002)
Communication costs	0.172(0.135)	− 0.025***(0.008)	0.013**(0.006)
Education	− 0.313***(0.031)	− 0.002(0.002)	− 0.002(0.002)
Village cadre	1.097***(0.307)	− 0.036***(0.013)	− 0.010(0.002)
Health	0.265***(0.103)	0.006(0.005)	0.014***(0.005)
Household size	0.035(0.039)	0.001(0.002)	0.001(0.002)
Internet usage	0.251(0.171)	0.060***(0.008)	0.009(0.011)
Expert	0.064(0.113)	− 0.013(0.008)	− 0.011**(0.005)
lntime	− 1.155***(0.099)		
Constant	− 3.065(1.778)	0.184*(0.108)	0.044(0.092)
Lns_1		− 2.955***(0.039)	
R_1		− 0.046(0.216)	
Lns_0			− 2.746***(0.041)
R_0			0.178**(0.086)
LR test of indep.eqns	3.08*		
Observations	623	623	623

The bracketed values are standard errors. The value of the variable "age square" is the age square of the household head divided by 100

The p values are in parentheses. ***, **, and * indicate 1%, 5%, and 10% significance levels, respectively

Table 5 Average treatment effects on farmers' safe production behaviors

Outcomes	Mean outcomes		ATT	T-value	Change(%)
	Member	Non-member			
Green control techniques	0.933	0.238	0.694***	99.270	74.491
Artificial weeding	0.276	0.169	0.107***	12.387	38.768
Organic fertilizer	0.145	0.111	0.033***	18.520	23.448

***, **, and * indicate 1%, 5%, and 10% significance levels, respectively

saving and environmentally friendly technical measures such as ecological regulation, biological control, physical control, and scientific pesticide use (Gao et al. 2019). GCT is a binary variable. GCT = 1 means adopting green control techniques, while GCT = 0 means not adopting the techniques. Artificial weeding is safer and more convenient than using herbicides, so it is considered one of farmers' safe production behaviors. Artificial weeding is also a binary variable, and artificial weeding = 1 means adopting the way of artificial weeding while artificial weeding = 0 means adopting other weeding methods. In addition, organic fertilizer which is derived from food waste, biomass or manure also contains high value of nutrients that can support crop growth (Lam and Lee 2012). In this paper, the amount of organic fertilizer input is a continuous variable and the unit is kg/mu.[4] Thus, ESP was used for estimating the effects of cooperative membership on farmers' behaviors of GCT and artificial weeding, while ESR was used for estimating the effects of cooperative membership on farmers' behaviors of organic fertilizer inputs.

[4] 1 mu is equal to 0.067 ha.

Treatment variable and controlled variable

The treatment variable in this paper is the behavior of farmers participating in rice cooperatives. This paper chose gender, age, marital status, number of siblings, communication cost, education, village cadre, health, household size, Internet usage, and the number of experts as control variables in the decision equation and outcome equation. The above control variables are the corresponding records for the actual situation of the householder. Gender, marital status, village cadre, and Internet usage age are binary variables; age, number of siblings, communication cost, education, health, household size, and the number of experts were measured as follows: actual age in 2019; the actual number of siblings; the natural logarithm of household head's communication cost in 2018; the actual years of education; very healthy =1, healthy = 2, general = 3, bad = 4, very bad = 5; the actual number of people in a household; the actual number of experts the household has.

Identification variable

Coromaldi (2015) have pointed out that in order to ensure the identification of the decision equation and the outcome equation, at least one control variable in the decision equation was not included in the outcome equation. For this purpose, this paper selected the time it took to the nearest economic organization away from home by car as the identification variable. Because the identification variable is found to be nonlinear with the dependent variable in the decision equation, the identification variable was measured as the natural logarithm of the time it took to the nearest economic organization away from home by car. Then, the effects of the identification variable on farmers' participation in rice cooperatives can be more intuitively observed. Except for the identifying variable, the control variables for the decision equation and the outcome equation are usually the same.

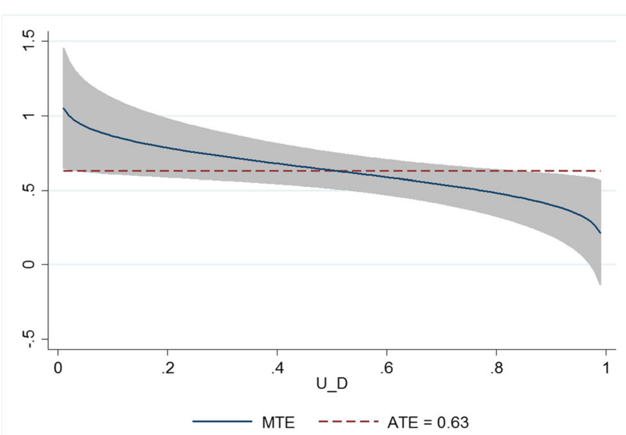

Fig. 2 Estimated MTE of cooperative membership on green control techniques

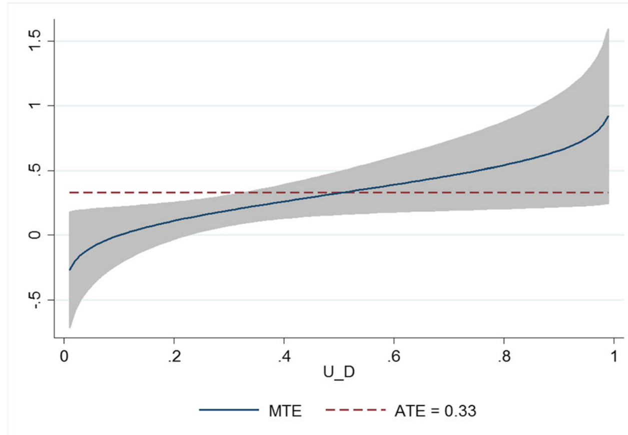

Fig. 3 Estimated MTE of cooperative membership on artificial weeding

Descriptive statistics

Table 1 shows the mean and standard deviation values of the key variables used in the paper, including the overall data description and the classified data description of membership and non-membership. The value of the difference is obtained from membership mean minus non-membership mean, and the *p* value is the test for the hypothesis that the difference is zero. From all sample data, most of the interviewed household heads are male, and the average age of household heads is 56.93 in good health. 92.3% of household heads are married; the average family size is four, and the number of siblings of the interviewees is three. The average educational level of household heads is around 4–5 years, and 79.8% of them use the Internet. In the aspect of farmers' safe production behaviors, 65.8% of farmers adopt green control techniques, reaching a much higher extent than artificial weeding, which is adopted by 18.1% of farmers.

When descriptive statistics of member and non-member rice farmers were compared, it found two points worth further analysis. First, the farmers who participated in rice

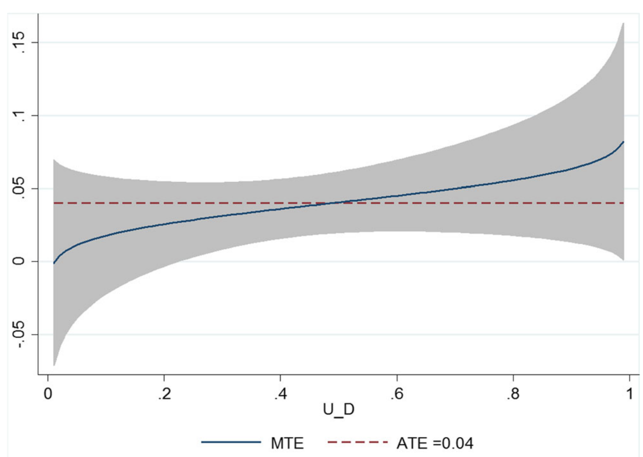

Fig. 4 Estimated MTE of cooperative membership on organic fertilizer input

cooperatives have more siblings, spend more on communications, with lower education level and better health condition than those who did not. Second, the safe production behaviors including green control techniques, artificial weeding, and organic fertilizer input of rice farmers who participated in cooperatives are significantly better than rice farmers who did not participate in cooperatives. The above significant differences indicate that there is a certain correlation between the participation of cooperatives and the adoption of safe production behaviors by rice farmers, and the specific impact needs to be further studied by ESR, MTE, and other methods.

Results and discussion

Effects of cooperative membership on farmers safe production behaviors

As shown in Table 2, the likelihood ratio test (LR test) was used to test the independence of the decision equation and the outcome equation. The result of the LS test is significantly non-zero at the 10% level, suggesting that the null hypothesis of independence should be rejected. Rho1 and rho0 in Table 2 are residual correlation coefficients which are used to observe the selectivity bias. Rho1 is the correlation coefficient between μ_i and ε_{i1}, and rho0 is the correlation coefficient between μ_i and ε_{i0}. Rho0 is significantly non-zero, indicating that there are unobservable factors that simultaneously affect GCT adoption and participation in cooperatives. The decision equation and the outcome equation are not independent, and the existence of selectivity bias indicates that the use of joint estimation of the ESP is valid.

In the estimation results of the decision equation, age, age square, marital status, education, village cadre, health, Internet usage, and the natural logarithm of the time it takes to the nearest economic organization away from home by car have significant effects on the rice farmers' participation in cooperatives. This is consistent with a previous study of Manda et al. (2020), which revealed the positive correlation between cooperative membership and the access to credit (in this study we use the natural logarithm of the time it takes to the nearest economic organization away from home by car), as cooperatives may charge poor members in the form of compulsory regular dues, alleviating liquidity restrictions through credit will increase the possibility of participating in cooperatives (Wossen et al. 2017). But the relationship between the decision to participate in cooperatives and education is against the result by Wossen et al. (2017), a probable explanation is that higher education levels may cause farmers to become more conceited, thereby reducing their dependence on cooperative organizations. However, gender, the number of siblings, the natural logarithm of communication cost, household size, and the number of experts have no significant effect on rice farmers' participation in cooperatives.

Comparing with the estimation results of the outcome equation, it is found that the influencing factors of GCT adoption are significantly different between member rice farmers and non-member rice farmers. For rice farmers who have not yet participated in cooperatives, the number of experts in their families has a significant positive impact on the GCT adoption, while age, communication cost, and household size have a significant negative impact on their GCT adoption. In general, the more experts are in a family, the easier to understand the importance of GCT adoption for growing green rice and protecting human health. Thus, it is more likely to adopt GCT. However, with the increase of farmers' age, their learning and cognitive ability gradually declines (Gao et al. 2019), and it becomes more difficult for them to identify and adopt GCT. Since farmers usually earn less, the higher the communication cost is, the less they spend on GCT, or even directly reject GCT. At the same time, the larger the household size is, the more likely the family members are to have disagreements, and the higher the probability of not adopting GCT. Once the rice farmers participate in cooperatives, the only factor that has a significant positive influence on farmers' GCT adoption is his (her) marital status. When the household head gets married, his (her) sense of responsibility to the family and society will increase, so he (she) will pay more attention to food health and be more willing to adopt GCT.

Table 3 presents the effects of cooperative membership on farmers' artificial weeding. The result of the likelihood ratio test (LR test) is significantly non-zero at the level of 5%, which means that the decision equation and outcome equation are not independent. Meanwhile, Both residual correlation coefficients rho1 and rho0 are significantly non-zero, indicating that there is selectivity bias and that some unobservable factors affect both rice farmers' choice of artificial weeding and their participation in cooperatives. Accordingly, it is appropriate to adopt the ESP model for econometric analysis of sample household data.

In the estimation results of the decision equation, age, age square, marital status, education, village cadre, health, Internet usage, and the natural logarithm of the time it takes to the nearest economic organization away from home by car significantly affect rice farmers' participation in cooperatives. However, gender, the number of siblings, the natural logarithm of communication cost, household size, and the number of experts do not significantly affect rice farmers' participation in cooperatives, and the possible reasons are the same as that of Table 2.

According to the estimation results of the outcome equation, whether or not rice farmers participate in cooperatives, gender has a significant negative effect on the artificial weeding. Also, age and Internet usage have significant negative effects on member rice farmers' artificial weeding, age square and education have significant positive effects on member rice farmers' artificial weeding. The reasons why these factors affect rice farmers' artificial weeding are as follows.

First, most men are less patient and careful than women, so artificial weeding is less likely chosen when the household is headed by a man. Second, by observing the different effects of age and age square on member rice farmers' artificial weeding, the "inverted u-shaped" influence mechanism of independent variables on dependent variables can be obtained. In other words, as household heads get older in the beginning, they would avoid the troublesome artificial weeding because they lack green consciousness and social responsibility. When the household heads' age beyond a certain threshold, their experience and sense of responsibility will deepen with age, and the household heads prefer to choose artificial weeding. Third, the higher the level of education, the stronger the cognitive ability of household heads, and they will be more likely to accept artificial weeding which benefits human health and is environmental friendliness. Fourth, however, the use of the Internet has made it easier for rice farmers to buy herbicides, which helps people save time and energy but hurts the environment and human health.

Table 4 shows the estimation results of the endogenous switching regression (ESR) model, which presents the effects of cooperative membership on organic fertilizer input. As shown in Table 4, the likelihood ratio test (LR test) is significantly non-zero at the level of 10%, indicating the null hypothesis that the decision equation and the outcome equation are independent should be rejected. Besides, the residual correlation coefficient x is significantly non-zero at the level of 5%, indicating that there are some unobservable factors simultaneously affect the organic fertilizer input and rice farmers' participation in cooperatives. Consequently, it is reasonable to use the ESR model to estimate the sample data.

According to the estimation results of the outcome equation, the factors that significantly affect the organic fertilizer input of member rice farmers and non-member rice farmers are completely different. For non-member rice farmers, increased communication costs and improved health can significantly increase the organic fertilizer input, while the increase in planting experts in households can significantly reduce the organic fertilizer input. Additionally, because experts have rich planting experience and scientific fertilization skills, the more planting experts a household has, the less organic fertilizer input will be. When rice farmers participate in cooperatives, Internet usage becomes the only factor that significantly increases organic fertilizer input, while the increase in the number of siblings, communication cost, and village cadre significantly reduce organic fertilizer input.

Average treatment effects of farmers' safe production behaviors

Table 5 shows the average treatment effect on the treated (ATT) of the effects of cooperative membership on farmers' safe production behaviors based on the estimations of ESP and ESR models. The estimation results of ATT are obtained by controlling for both observable and unobservable factors. First of all, the treatment effect values of member and non-member rice farmers' GCT are respectively 0.933 and 0.238. The ATT of the effects of cooperative membership on farmers' GCT adoption is 0.694, with a change by 74.5%, indicating that if these farmers who joined the cooperative did not join the cooperative, the adoption of GCT would be reduced by 74.5%. In addition, the treatment effect of artificial weeding reveals that not joining a cooperative would reduce the rate of artificial weeding by cooperative members by 38.8%. Moreover, the treatment effect values of member and non-member rice farmers' organic fertilizer input are respectively 0.145 and 0.111. The calculated result of the change between the two values indicates that if they did not join the cooperative, the farmers who joined the cooperative would reduce their organic fertilizer input by 23.4%. In summary, the all estimation results above present that the cooperative membership has significantly positive effects on farmers' safe production behaviors. Those results are consistent with the received environmental economics literature that collective action has positive effects on safe production (Ji et al. 2018; Ji et al. 2019). The biggest difference from existing literature on the safe production of pig farmers is that this paper focuses on the safe production of rice farmers. Overall, the existing literature suggests that the farmer cooperative is a very important carrier for smallholder farmers to gain the power of collective action in improving farmers' access to agricultural assets as well as credit (Fischer and Qaim 2012), providing smallholder farmers with information, technical assistance and proper inputs at a relatively lower price (Naziri et al. 2014), and achieving more stable sales and possibly at a better price (Ji et al. 2012; Mojo et al. 2017). Therefore, the farmer cooperative creates a favorable condition for smallholder farmers with cooperative membership to achieve safe production of rice.

Expected effects on safe production behaviors of rice farmers

The estimation of MTEs is an approach used in empirical research when the impact of a treatment is thought to vary within a population in correlation with unobserved characteristics (Brave and Walstrum 2014). Rice farmers are different in the unobservable characteristics such as personality traits, learning ability, and market insight. It is reasonable to believe there is unobservable heterogeneity in the effects of cooperative membership on farmers' safe production behaviors. To investigate the heterogeneity, MTEs (at the mean value of all covariates in X) are estimated along the 99 percentile points of the distribution of unobservable UD (Ferreira Sequeda et al. 2018). The MTEs describe whether safe production behaviors of rice farmers on the margin of cooperative membership increase or decrease with the probability of participating in cooperatives. The estimated results show that the model fits well and it is correct to consider unobservable heterogeneity.

The calculation results of MTE of farmers' GCT adoption are shown in Fig.2 and Table 6 in Appendix 1. Compared with the results in Table 5, the estimated ATE is also significantly positive and reduces from 0.694 to 0.633. According to the analysis method used by Heckman and Vytlacil (2005), in Fig.2 MTE estimations of the low UD values show the expected effects of GCT adoption of rice farmers who are more likely to participate in cooperatives due to undetectable factors. Thus, the high UD values in Fig. 2 represent the rice farmers who are more likely not to participate in cooperatives. The downward-sloping shape of the MTE curve in Fig. 2 presents that the probability of GCT adoption decreases when rice farmers who are more likely not to participate in cooperatives but actually participate in (high UD values). It means that rice farmers who are not interested in participating in cooperatives are less likely to adopt GCT. In other words, rice farmers who want to participate in cooperatives are more active in using information and resources from the cooperatives to adopt GCT.

Figure 3 and Table 7 in Appendix 1 show the calculation results of the MTE of farmers' artificial weeding. Compared with the results in Table 5, the estimated ATE is also significantly positive and increases from 0.107 to 0.327. In Fig. 3, MTE estimations of the low UD values show the expected effects of artificial weeding of rice farmers who are more likely to participate in cooperatives due to undetectable factors. High UD values in Fig. 3 represent rice farmers who are more likely not to participate in cooperatives. The upward-sloping shape of the MTE curve in Fig. 3 indicates the ATE of cooperative membership is higher for rice farmers who are more likely not to participate in cooperatives (high UD values). The reason is that those rice farmers have a strong personal ability and believe that they can make decisions and money independently without relying on cooperatives. When they finally participate in cooperatives for a variety of reasons, the practical help they get from the cooperative will promote the realization of artificial weeding.

Figure 4 and Table 8 in Appendix 1 show the calculation results of the MTE of farmers' organic fertilizer input. Compared with the results in Table 5, the estimated ATE is also significantly positive and increases from 0.033 to 0.041. In Fig. 4, MTE estimations of the low UD values show the expected effects of organic fertilizer input of rice farmers who are more likely to participate in cooperatives due to undetectable factors. High UD values in Fig. 4 represent rice farmers who are more likely not to participate in cooperatives. The upward-sloping shape of the MTE curve in Fig. 4 indicates the ATE of cooperative membership is higher for rice farmers who are more likely not to participate in cooperatives (high UD values). It means that even though these reluctant rice farmers eventually participate in cooperatives, they would not actively learn scientific fertilization techniques from cooperatives and their organic fertilizer input is higher.

Robustness test

In this section, we employ a propensity score matching method to check the robustness of our results. Before matching scores, the balance of matching is firstly tested. The distribution of predicted propensity scores for member and non-member rice farmers shows a large common support for propensity scores among member and non-member rice farmers (Appendix 2 Fig. 5 and Fig. 6). High-quality matching enhances the confidence in matching estimation. The tables are listed in Appendix 2 Table 9 and Table 10.

Table 11 in Appendix 2 shows the estimated results of the effects of cooperative membership on farmers' safe production behaviors by using NNM and KBM methods to match propensity scores. It suggests that whether using the NNM method or the KBM method, cooperative membership has significantly (1% level) positive effects on farmers' three safe production behaviors.

Moreover, to check the effects of unobservable factors on PSM estimation results, Rosenbaum bounds sensitivity analysis is selected to evaluate the sensitivity of PSM results to the assumption of the importance of unobservable factors relative to the observable factors in affecting farmers' cooperative participation decision (Ji et al. 2019), so as to test the robustness of PSM model. If PSM estimation results are less sensitive to the increase in the importance of unobservable variables relative to the observable variables, the results are more reliable.

The results of bound analysis are presented in Appendix 2 Table 11. Γ=1.0 is the benchmark scenario when there is no selectivity bias due to unobservable factors. A bigger Γ value means the presence of a bigger hidden bias. A significant upper (or lower) bound means that the PSM estimation effects of cooperative membership are still significant even with some degree of hidden bias. The results of the whole sensitivity analysis are highly consistent with the results of the t-statistic in Table 11. It is worth noting that the results of the three safe production behaviors are all significant at the 1% level as the Γvalue increases from 1.0 to 2.0. In other words, farmers' safe production behaviors are insensitive to the hidden bias, indicating that the estimation results of the PSM model are very robust. As a result, it can be confirmed that cooperative membership can effectively promote farmers to adopt safe production behaviors. And then it can be further concluded that the results obtained by using ESP and ESR models which are consistent with PSM results are also robust.

Conclusion and policy implication

The grain output growth in China largely benefits from the application of chemical fertilizer and pesticides. However, overuse of chemical fertilizer and pesticides has led to serious environmental problems, such as soil degradation, air pollution, water contamination, and the presence of pesticide residues in food. Not only does it bring huge damage to human health, but also it threatens sustainable development of agriculture. Therefore, how to address environmental issues arising from the overuse of chemical fertilizer and pesticides has been a severe challenge faced by China for decades. In recent years, the rise of rural cooperative organizations has played a vital role in agricultural production, especially in promoting the transformation of agricultural production model. Same with the most typical rural cooperative organization in China, the farmer cooperative is regarded as the most important vehicle for farmers to take collective action to solve problems mentioned above. Therefore, the participation in farmer cooperatives might contribute to safe production in rice agriculture. However, there is little empirical evidence on the effects of the participation in farmer cooperatives on safe production in rice agriculture in China.

Using cross-sectional survey data covering 623 rice-producing farm households in Sichuan in China, this study employs an endogenous switching regression model to investigate the causal relationship between the participation in farmer cooperatives and safe production behaviors among smallholders in rice agriculture. The empirical results show a positive and significant relationship between cooperative membership and safe production in rice agriculture. To be more precise, the participation in farmer cooperatives tends to promote adoption of the green control techniques, artificial weeding, and organic fertilizer input among the rice-producing farm households in China. In particular, the positive effects of the participation in farmer cooperatives on safe production, differentiated by willingness to participate in farmer cooperatives, reveal that the effects on adoption of the green control techniques are significantly higher among rice farmers with cooperative membership who are more likely to participate in farmer cooperatives due to their unobservable characteristics. While, the effects on adoption of artificial weeding and organic fertilizer are significantly higher among rice farmers with cooperative membership who are less likely, due to unobserved reasons, to participate in farmer cooperatives.

The results in this study have crucial policy implications for promoting the adoption of safe production among smallholders in China. First, the government should encourage and support smallholder farmers to participate in farmer cooperatives. The existing literature has documented that farmer cooperatives can play a positive role in improving the bargaining power of smallholder farmers, reducing the cost of agricultural inputs and enhancing provision of credit and information (Beyene and Kassie 2015). As the most important vehicle for collective action among smallholder farmers, farmer cooperatives would greatly mitigate the constraints faced by smallholder farmers, encourage them to achieve safe production such as adoption of green control techniques, artificial weeding, and organic fertilizer. Second, our results show that the effects of cooperative membership on safe production among smallholder farmers are heterogeneous as farmers' willingness to participate in the cooperative are different. The above differences are associated with their unobservable characteristics, such as risk preference. Therefore, the government should analyze the limiting factors or barriers of farmers to participate in cooperatives and adopt safe production and take effective measures to strengthen the ability of farmers to be eligible for cooperative membership and adopt safe production, which is regarded as an innovation in rice production, provide farmers with information on the benefits of safe production.

Future studies should address a number of issues related to this study. First, future studies need to improve the external validity of this research by examining similar issues in a broader set of locations across China or in different time periods or crops. Second, future studies need to explore the causal mechanisms underlying the relationship between cooperative membership and safe production among smallholder farmers, and this will shed further light on what measures should be chosen to promote adoption of safe production in agriculture.

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Author contributions Houjian Li and Kaihua Yuan conceived and designed this research; Yu Liu and Xuemei Zhao drafted the manuscript and prepared figures; Lichen Zhang discussed the results. All authors have read and agreed to the submitted version of the manuscript.

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Data availability The authors do not have permission to share data.

Compliance with ethical standards

Ethics approval and consent to participate The experimental protocol was established, according to the ethical guidelines of the Helsinki Declaration, and was approved by the Human Ethics Committee of Sichuan Agricultural University. Written informed consent was obtained from individual or guardian participants.

Consent for publication The work described has not been published before (except in the form of an abstract or as part of a published lecture, review, or thesis); it is not under consideration for publication elsewhere; its publication has been approved by all co-authors, if any; its publication has been approved (tacitly or explicitly) by the responsible authorities at the institution where the work is carried out.

Competing interests The authors declare that they have no competing interests.

Appendix 1

Table 6 MTEs estimation and standard errors of farmers' GCT adoption

U_D 1	1.051***	U_D 30	0.727***	U_D 60	0.588***	U_D 90	0.403***
	(0.205)		(0.081)		(0.059)		(0.105)
U_D 10	0.864***	U_D 40	0.679***	U_D 70	0.539***	U_D 99	0.215***
	(0.129)		(0.068)		(0.065)		(0.178)
U_D 20	0.784***	U_D 50	0.633***	U_D 80	0.482***		
	(0.099)		(0.060)		(0.079)		
ATE	0.633***	rho1-rho0	− 0.280**				
	(0.060)		(0.078)				

ATE refers to average treatment effect

*, **, and *** indicates that the corresponding *p* values less than 1%, 5%, and 10% respectively

Table 7 MTEs estimation and standard errors of farmers' artificial weeding

U_D 1	− 0.266	U_D 30	0.193***	U_D 60	0.391***	U_D 90	0.653***
	(0.227)		(0.059)		(0.107)		(0.220)
U_D 10	0.001	U_D 40	0.262***	U_D 70	0.461***	U_D 99	0.919***
	(0.111)		(0.065)		(0.135)		(0.342)
U_D 20	0.113	U_D 50	0.327***	U_D 80	0.541***		
	(0.072)		(0.083)		(0.170)		
ATE	0.327***	rho1-rho0	0.255**				
	(0.083)		(0.119)				

ATE refers to average treatment effect

*, **, and *** indicates that the corresponding *p* values less than 1%, 5%, and 10% respectively

Table 8 MTEs estimation and standard errors of farmers' organic fertilizer input

U_D 1	− 0.001	U_D 30	0.031***	U_D 60	0.045***	U_D 90	0.064**
	(0.036)		(0.012)		(0.012)		(0.025)
U_D 10	0.018	U_D 40	0.036***	U_D 70	0.050***	U_D 99	0.082**
	(0.020)		(0.010)		(0.015)		(0.041)
U_D 20	0.026*	U_D 50	0.041***	U_D 80	0.056***		
	(0.015)		(0.010)		(0.020)		
ATE	0.041***	rho1-rho0	0.018				
	(0.010)		(0.016)				

ATE refers to average treatment effect

*, **, and *** indicates that the corresponding *p* values less than 1%, 5%, and 10% respectively

Appendix 2

Table 9 PSM quality indicators before and after matching

Variable	Unmatched/matched	% |bias| reduction		t test ($p > t$)	
		NNM	KBM	NNM	KBM
Gender	U			0.532	0.532
	M	65.8	94.4	0.797	0.967
Age	U			0.334	0.334
	M	−83.3	−119.2	0.036	0.014
Age square	U			0.252	0.252
	M	−63	−103.8	0.029	0.008
Married	U			0.154	0.154
	M	60.1	55.2	0.461	0.402
Siblings	U			0.081	0.081
	M	8.8	71.3	0.051	0.554
Communication cost	U			0.000	0.000
	M	90.3	95.3	0.252	0.588
Education	U			0.890	0.890
	M	9.1	−165.9	0.883	0.658
Cadre	U			0.001	0.001
	M	89.2	92.9	0.664	0.779
Health	U			0.583	0.583
	M	−23	−99.2	0.400	0.186
Household size	U			0.041	0.041
	M	86.8	73.8	0.752	0.523
Internet usage	U			0.003	0.003
	M	36	59.8	0.022	0.156
Expert	U			0.022	0.022
	M	55.1	56.8	0.217	0.239

Matching algorithm: nearest neighbor matching (NNM) and kernel based matching (KBM)

Table 10 PSM quality indicators before and after matching

Method	Sample	Ps R^2	LR chi2	$p >$ chi2	Meanbias	Medbias	*B*	*R*	%Var
RAW	Unmatched	0.243	209.27	0.000	22.3	12.6	126.3*	0.65	88
NNM	Matched	0.031	26.77	0.008	11.6	9.7	41.9*	0.93	50
KBM	Matched	0.019	20.59	0.113	8.3	4.8	32.6*	0.82	60

***, **, and * indicate 1%, 5%, and 10% significance levels, respectively

Table 11 PSM regression results of behavioral difference between members and non-members

Outcome variable	Matching method	Sample	Treated	Controls	Difference	*T* value	Γvalue
Green control techniques	NNM	ATT	0.929	0.401	0.528	7.70***	≥2
		ATE			0.040	5.76***	≥2
	KBM	ATT	0.932	0.372	0.560	10.42***	≥2
		ATE			0.045	7.52***	≥2
Artificial weeding	NNM	ATT	0.282	0.032	0.249	5.82***	≥2
		ATE			0.288	6.47***	≥2
	KBM	ATT	0.275	0.060	0.214	6.03***	≥2
		ATE			0.281	7.28***	≥2
Organic fertilizer	NNM	ATT	0.144	0.111	0.033	4.08***	≥2
		ATE			0.554	11.79***	≥2
	KBM	ATT	0.144	0.102	0.042	6.42***	≥2
		ATE			0.574	14.52***	≥2

***, **, and * indicate 1%, 5%, and 10% significance levels, respectively

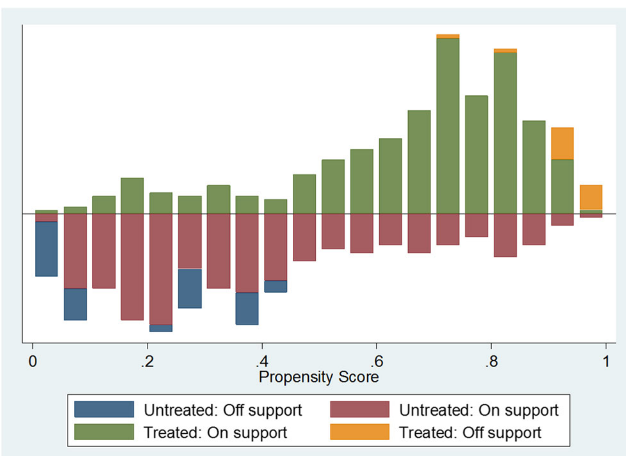

Fig. 5 The nearest neighbor matching based on the estimated propensity score

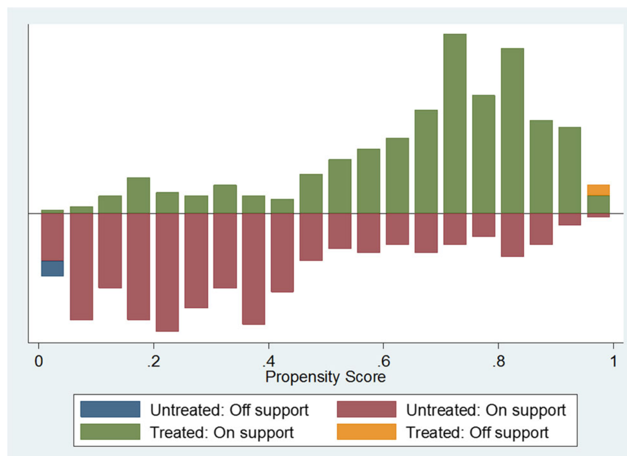

Fig. 6 The kernel matching based on the estimated propensity score

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