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RESEARCH ARTICLE

Does agricultural cooperative membership help reduce the overuse of chemical fertilizers and pesticides? Evidence from rural China

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Abstract

The overuse of chemical fertilizers and pesticides (CFPs) has negatively impacted the environment and human health. It is an urgent issue that should be addressed. In this study, we investigate whether agricultural cooperatives can serve as an institutional arrangement that helps reduce the consumption of CFPs, using the data of 2012 family farms from the Ministry of Agriculture and Rural Affairs of China. Various approaches, including instrumental variable-based two-stage residual inclusion approach (2SRI), endogenous switching probit (ESP) model, and endogenous switching regression (ESR) model, are utilized to help address the endogeneity issues of the cooperative membership variable. The results show that agricultural cooperative membership significantly increases the probability of reducing fertilizers and pesticides of the family farms and improves net return per yuan CFPs. The further analysis shows that agricultural cooperative production services reduced the usage of fertilizers and pesticides, while cooperatives marketing services only significantly lowered the use of pesticides. Our findings highlight the importance of promoting the development of agricultural cooperatives to support green agricultural production in China.

Keywords Agricultural cooperative · Fertilizers · Pesticides · Family farm · Endogeneity · China

JEL classification D13 · J54

Introduction

The issues of overusing chemical fertilizers and pesticides (CFPs) exist in many developing countries. In their survey in Bangladesh, Dasgupta et al. (2007) found that more than 47% of farmers overuse pesticides among farmers producing rice, potato, bean, eggplant, cabbage, sugarcane, and mango. Grovermann et al. (2013) showed that about 80% of vegetable farmers had used pesticide quantity excess of the social optimum. Schreinemachers et al. (2020) investigated vegetable production in Southeast Asia, and they found that 100% of the sampled farmers in Vietnam, 73% in Cambodia, and 59% in Laos overused pesticides, challenging the environmental performance and the health of human beings.

China had 8.57% of world farmland but consumed 24.97% fertilizers (by nutrients) and 43.03% pesticides in 2018 (FAOSTAT). Low application efficacy is one reason contributing to the overuse of CFPs (Huang et al. 2021; Li et al. 2019; Wang and Liu 2021; Wu et al. 2018; Zhao et al. 2021; Zheng et al. 2019). Wu et al. (2018) reported that the average use efficacy of nitrogen fertilizer in wheat, rice, and maize production in China is 31%, compared with 53–63% in North America and Europe. Long-term overuse of CFPs causes food safety concerns and severe non-point pollution issues, challenging sustainable agricultural production (Huang et al. 2018; Huang and Jiang 2019; Li et al. 2020a, b; Meng et al. 2020; Pan et al. 2020; Wang et al. 2020; Zheng et al. 2021a; Zhou et al. 2018a, b). Overusing chemical fertilizers and pesticides (CFPs) needs immediate, practical solutions in China to ensure food safety and environmental sustainability. Therefore, China has taken a series of measures to increase

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the CFPs utilization rate and reduce the quantity to promote sustainable agricultural production. The Chinese government also has issued a series of policies to regulate the application of the CFPs and develop green agrarian production.

About 200 million very small part-time farmers in China practice farming based on traditional experience but not modern agricultural technologies. The knowledge and resource constraint they face is the primary cause of the misuse or overuse of CFPs (Zheng et al. 2020; Zhou et al. 2016; Zhou and Jin 2009). As a prominent business institutional form in the world agri-food system, agricultural cooperatives play a crucial role in organizing smallholder farmers to increase production scale and skill worldwide (Cai et al. 2016; Cook and Iliopoulos 2013; Ito et al. 2012; Ma et al. 2018b; Ma and Zhu 2020; Minah 2021; Mnisi and Alhassan 2021; Molla et al. 2020; Su and Cook 2020; Zhang et al. 2020). The Chinese government supports a healthy agricultural cooperatives system to provide agricultural extension services and marketing services. For example, China has issued the *Law of Farmers' Professional Cooperatives* in 2007 and adopted a series of supporting measures to promote the sustainable development of agricultural cooperatives. Among the series of agricultural and environmental-related policies and regulations from 2015 to 2020, the Chinese government encouraged and emphasized promoting sustainable agriculture with appropriate use of CFPs through the agricultural cooperative business system. Because the average farm size is less than 0.4 ha in China and the majority incomes of smallholder farms are from off-farm work, they lack incentives to join agricultural cooperatives. In response, China has begun to nurture larger-scale and more professional family farms and implemented the "family farm nurturing program" to provide a strong foundation for modern agriculture development since 2018.

Most Chinese agricultural cooperatives have multi-purposes and play three core functions: marketing products, purchasing supplies, and providing services (Su and Cook 2020). Providing services and marketing products are equally crucial for agricultural cooperatives and their farmer members. Many marketing cooperatives contract with supermarkets to sell their members' products under the supply chain model of "farmers plus cooperatives plus supermarkets" (Cai and Ma 2015; Chen et al. 2013; Gong et al. 2019). Under this marketing channel, agricultural cooperatives established strict quality standards, including residual levels of fertilizers and pesticides, to meet their buyers' quality demand. Many agricultural cooperatives provide comprehensive services such as input purchase, production training, technique consultation, and field services to help farmers follow those required standards. Therefore, these agricultural cooperatives play critical roles in controlling the use of CFPs to ensure agrarian products safety.

Some studies have shown significant positive impacts of cooperative membership on the adoption of agricultural technologies in China (Chen et al. 2013; Liu et al. 2019; Ma et al. 2018b; Ma and Abdulai 2019; Manda et al. 2020; Yu et al. 2021; Zhang et al. 2020; Zhou et al. 2016; Zhou and Jin 2009). For example, Ma et al. (2018b) showed that agricultural cooperative members are more likely to adopt organic fertilizer and farmyard manure in China's apple production. Agricultural cooperatives supply inputs and provide embedded support and training services to make their farmer members technically more efficient. The training effects worked through the following mechanisms. First, good farming practices increase the application efficacy of CFPs and restrict highly toxic pesticides (Zhou and Jin 2009). The second was that farmers substituted chemical fertilizers with organic fertilizers. The other was soil management and integrated pest management (IPM), which reduces the amount needed for CFPs (Ma et al. 2018a; Ma and Abdulai 2019). Besides, effective communication between agricultural cooperative and members, trust in the agricultural cooperatives' management team, and the collective organization objectives all are critical for the farmers to practice good agricultural practices (GAP) and follow the CFPs use standards of the agricultural cooperative (Liu et al. 2019; Zhou et al. 2016; Zhou and Jin 2009). Nevertheless, the studies mentioned above mainly focused on smallholder fruit and vegetable farmers, with little attention paid to grain and larger-scale producers. To the best of our knowledge, no previous studies have considered the service-oriented characteristics of Chinese agricultural cooperatives.

The primary objective of this study is to analyze the impacts of cooperative memberships on reducing the overuse of CFPs for large-scale specialized family farms. We use data of 2012 family farms collected by the Ministry of Agriculture and Rural Affairs of China.[1] As a further contribution, we employ various approaches, including instrumental variable-based two-stage residual inclusion (2SRI) approach, endogenous switching probit model, and endogenous switching regression model, to address the endogeneity issues of the cooperative membership variable. These approaches have significant advantages over other common regression techniques such as ordinary least-square (OLS), probit methods, or propensity score matching (PSM) approach. In particular, the 2SRI approach can also help obtain more accurate asymptotically correct standard errors (ACSE) for testing t statistics. Our results show that agricultural cooperatives can be an institutional arrangement that helps reduce agrochemicals in rural China.

China is an interesting example. Globally, China is the largest pesticide consumer, followed by the USA, Brazil, Argentina, and Canada (FAOSTAT). It is also the largest fertilizer consumer globally, followed by India, the USA, Brazil, and Pakistan (FAOSTAT). Figures 1 and 2 show that pesticides and nitrogen fertilizer for agricultural use increase from

[1] It was named Ministry of Agriculture before 2018.

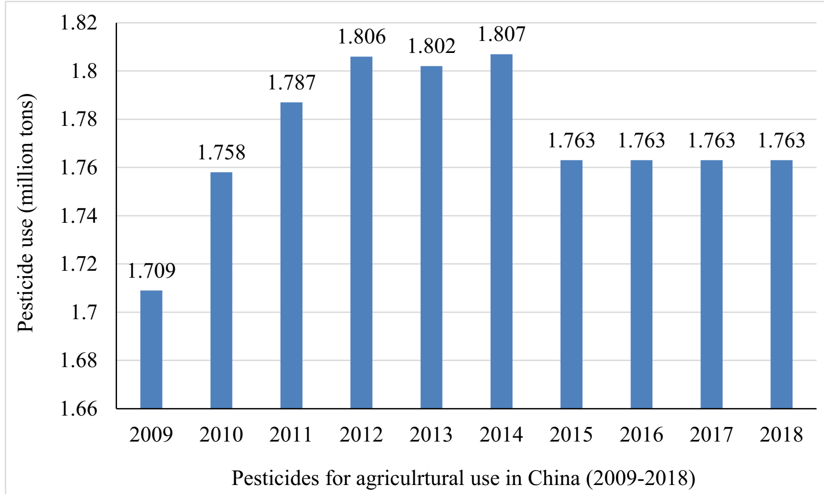

Fig. 1 Pesticides for agriculrtural use in China (2009–2018)

2009 to 2014. Specifically, pesticide use increased from 1.709 million to 1.807 million t, and nitrogen fertilizer use increased from 29.130 million to 31.145 million tons. Afterwards, due to the implementation of the “Action Plans to Achieve Zero Growth of Chemical Pesticides and Fertilizers by 2020” by the Chinese government in 2015, pesticide use level does not change from 2015 to 2018 level of nitrogen fertilizer use reduces during the same period. Because pesticide and fertilizer use pollutes the environment and challenges the health of human beings, it is significant to understand whether agricultural cooperatives can help reduce their applications of farm sectors.

The remainder of the paper is structured as follows. “Analytical framework and hypotheses” section presents the analytical framework and hypotheses. “Methods and data sources” section discusses the methods and data sources, and the empirical results and discussions follow this in “Empirical results and discussions” section. The final section concludes and discusses policy implications.

Analytical framework and hypotheses

Agricultural cooperatives in China provide multiple functions to their members. Two important ones are to give guidance of conducting the normative and specialized production (Li et al. 2021; Ma et al. 2018b; Mnisi and Alhassan 2021; Molla et al. 2020; Serra and Davidson 2021; Zhou et al. 2018a, b) and to promote the coordination between “small production” of single farms and socialized “big markets” (Agbo et al. 2015; Kontogeorgos et al. 2018; Liu et al. 2019; Minah 2021; Mnisi and Alhassan 2021; Molla et al. 2020; Paudel and Acharya 2021; Sebhatu et al. 2021). The overuse of CFPs causes severe food quality and safety problems in China and makes consumers lack Chinese food confidence. Under this circumstance, agricultural cooperatives are motivated to guide their farmer members to eliminate the use of highly toxic pesticides and avoid the overuse of agricultural chemicals to ensure food safety and quality. Two critical agricultural cooperative functions, including production services and marketing, help reduce the overuse of CFPs.

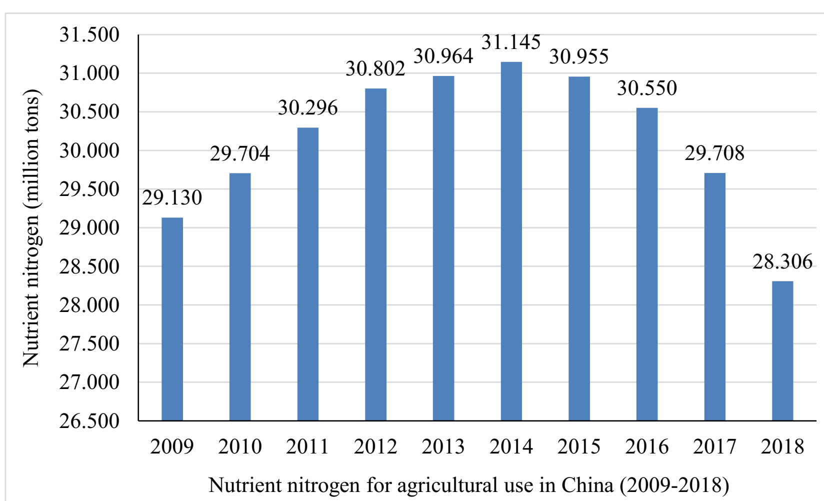

Fig. 2 Nutrient nitrogen for agricultural use in China (2009–2018)

Production perspective

Mimetic effect

The social learning theory of Bandura (1977) states that people tend to observe and imitate the behaviors of their peers in a particular circumstance. Gathering information from peers or observing neighboring farms' production behaviors is the primary way for farmers to obtain information and new agricultural technologies (Chavas and Nauges 2020; Grace 2018; Takahashi et al. 2020; Zhang et al. 2020). After participation in agricultural cooperatives, farmers form a social community and formal network relation with trusted weak ties, which could strengthen the diffusion and communication of new skills and useful knowledge (Fisher et al. 2018; Leta et al. 2018) and thereby promote the completion of imitation process (Oehme and Bort 2015). Observing and imitating agricultural cooperative peers and technical experts regarding proper practices can help smallholder farmers reduce the misuse or overuse of CFPs. Zhou and Jin (2009) examined the usage of highly toxic pesticides of 507 produce farmers. They found the farmers who imitated their peers' good practice significantly more likely eliminated the misuse of pesticides than those who did not.

Normative effect

It is well acknowledged that norms influence groups and individuals' behaviors greatly. Reed and Hickey (2016) found that formal vertical linkage is the predominant channel of innovation spread in agricultural cooperatives. In 2017, the Chinese State Council approved the amendment to the "Regulation on the Administration of Pesticides". It restated its previous regulation to require the cooperatives to record the information of all agricultural chemicals applied accurately. Therefore, many agricultural cooperatives have established formal standards for their members' chemical inputs, especially pesticide use (Zhou et al. 2019). Ito et al. (2012) revealed that a watermelon cooperative in Nanjing, Jiangsu province, established a detailed chemical application protocol and paid 20% premiums to the producer members who followed the protocol.

Specialized effect

Compared with individual farms, agricultural cooperatives can obtain economies of scale by pooling the resources and improving agricultural production specialization (Yang and Liu 2012). Chinese agricultural cooperatives provide input purchase, professional production services from planting to harvest, and marketing. Producers adopted good production practices and minimized the overuse of CFPs with the agricultural cooperative service team's help. Li et al. (2014) pointed out that pesticide spraying conducted by specialized agricultural cooperatives contributed to ecological environment protection. In China's Heilongjiang province, 1481 agricultural cooperatives supply professional fertilizer application using advanced application machinery and precision farming technology. Consequently, the consumption of fertilizers in Heilongjiang province was reduced by 10% in the leading crops, such as soybean, corn, and rice.[2]

Marketing perspective

High chemical residues create food safety concerns for Chinese agri-products and prevent Chinese farmers from benefiting from international markets (Alita et al. 2020; Liu and Guo 2019; Lu et al. 2015). Improving the food safety of agricultural products is an essential task for agricultural cooperatives required by the Chinese government.

Agricultural marketing cooperatives aggregate market farm products collectively (Hao et al. 2018; Liu et al. 2019). They have the incentives to meet the market demands of high-quality, safe agricultural food products. Many agricultural cooperatives have signed sales contracts with supermarkets or food manufacturers with specific quality standards under the government's support. Consequently, these agricultural cooperatives set up strict quality standards and require their farmer members to follow them. Additionally, agricultural cooperatives employees supervise the production and monitor their members' production behaviors to ensure their products meet the food safety standards by appropriate use of CFPs (Chen et al. 2013; Giagnocavo et al. 2017; Zhou et al. 2018a, b). Chen et al. (2013) investigated the marketing cooperatives selling to 24 supermarkets in China's Beijing and found that these cooperatives hired professional technicians to teach farmer members to use the best pesticide practices. These agricultural cooperatives also conducted pesticide residue tests and heavy metal tests for all products they purchased from their members to ensure quality and safety.

High-quality products ensure the cooperatives achieve high profits. Some agricultural cooperatives have gradually created their agri-products brands and internalized more external profits (Grashuis 2019; Liu et al. 2019; Sexton and Xia 2018; Zhang et al. 2020). According to the cooperatives' requirements, joining agricultural cooperatives and reducing the consumption of CFPs create more profits for cooperative members (Ito et al. 2012; Liu et al. 2019; Ma and Abdulai 2019). Hence, cooperative members have the incentives to reduce the overuse of agricultural chemicals, especially pesticides, to satisfy the cooperatives' quality standards. Ma and Abdulai (2019) studied 481 apple producers in China's Gansu, Shanxi, and Shandong provinces. They concluded these producers were willing to adopt IPM technology and

[2] Source: http://hlj.people.com.cn/n2/2018/1211/c220024-32394255.html

follow the production protocol established by their cooperatives to reduce chemical pesticide use and get higher net returns.

Based on the discussions above, this study attempts to test the two hypotheses illustrated below:

H1: Good production practices reduce the use of chemical fertilizers and pesticides in agricultural cooperatives in rural China.

H2: Marketing-related activities reduce the use of chemical fertilizers and pesticides in agricultural cooperatives in rural China.

Methods and data sources

Econometric model

Our first objective is to identify the determinants of farmers' participation in an agricultural cooperative. Following previous studies (e.g., Li et al., 2020b; Ma and Abdulai 2019; Meng et al. 2020; Mojo et al. 2017; Zheng et al. 2021a), the random utility framework analyses farmers' decision to join an agricultural cooperative. We assume that a rational farmer i will join an agricultural cooperative when the utility of being a member U_i^m is larger than the utility U_i^n of not being a member. However, the actual utility levels of a farmer are not observable. But the utility gain, which is defined as $C_i^* = U_i^m - U_i^n$, can be expressed as a function of a vector of observable explanatory variables Z_i in the following latent variable model:

$$C_i^* = \beta Z_i + \varepsilon_i, \text{where } C_i = 1 \text{ if } C_i^* > 0 \text{ and } C_i = 0 \text{ if } C_i^* < 0 \quad (1)$$

where C_i^* refers to the probability that a farmer chooses to join an agricultural cooperative, which is determined by an observed variable C_i. In particular, $C_i = 1$ if a farmer has obtained cooperative membership, and $C_i = 0$ otherwise. Z_i is a vector of factors affecting farmers' decisions to participate in an agricultural cooperative; β is the parameters to be estimated, and ε_i is the disturbance term assumed to be normally distributed with zero means.

The probability of a farmer joining an agricultural cooperative is given as follows:

$$Pr(C_i = 1) = Pr(\varepsilon_i > -\beta Z_i) = 1 - F(-\beta Z_i) \quad (2)$$

where F is the cumulative distribution function for ε_i.

To link the agricultural cooperative membership with the usage of CFPs, we assume that the usage of CFPs is a linear function of a vector of covariates X_i and the dichotomous membership variable C_i, expressed as follows:

$$Y_i = \alpha X_i + \gamma C_i + \mu_i \quad (3)$$

where Y_i represents a vector of outcome variables of farmer i such as chemical fertilizer reduction, pesticide reduction, and application efficacy of CFPs, defined as the net return per yuan[3] cost of CFPs. α and γ are parameters to be estimated; μ_i is the disturbance term.

In Eq. (3), the agricultural cooperatives membership variable C_i is potentially endogenous because farmers' decisions to be cooperative members and non-members are affected by observed factors (e.g., age and education) and unobserved factors (e.g., farmers' innate abilities and motivations). Hence, the disturbance term ε_i in Eq. (1) and disturbance term μ_i in Eq. (3) may be correlated. If the correlation coefficient does not equal zero, i.e., corr(ε_i, μ_i) $\neq 0$, selection bias occurs. Standard regression techniques, such as ordinary least-square (OLS) and probit models, fail to account for such selection bias and tend to produce inconsistent estimation results. Both propensity score matching (PSM) method and the inverse probability weighted regression Adjustment (IPWRA) estimators address the selection bias, but they do not account for the unobservable selection bias issue (Chagwiza et al. 2016; Manda et al. 2018; Michalek et al. 2018; Zheng and Ma 2021). In comparison, the two-stage residual inclusion (2SRI) approach addresses the selection biases arising from both observed and unobserved factors (Terza 2016; Ying et al. 2019; Zheng et al. 2021b; Zhu et al. 2020). Besides, the 2SRI method can directly investigate the influence of unobservable factors and obtain asymptotically correct standard errors (ACSE) for testing t statistics. This study employs the 2SRI approach to conduct empirical analysis.

In the 2SRI method, the residual term obtained from Eq. (1) estimation is included in Eq. (3) as an additional explanatory variable. Hence, Eq. (3) is reformulated as follows:

$$Y_i = \alpha X_i + \gamma C_i + \varphi R_i + \mu_i \quad (4)$$

where R_i represents the residual term estimated from Eq. (1).

For robustness check and estimating the average treatment effect on the treated (ATT), both the endogenous switching probit (ESP) model and the endogenous switching regression (ESR) model are also estimated. Specifically, in consideration of the nature of the dependent variables, we use the ESP model to evaluate the impact of agricultural cooperative membership on fertilizer reduction and pesticide reduction and employ the ESR model to assess the impact of cooperative membership on CFPs use efficacy (Ma and Zhu 2020).

To identify 2SRI, ESP, and ESR models and improve parametric estimations, Z_i in Eq. (1) should contain X_i plus at least one instrumental variable (IV) that affects the decision of

[3] The yuan is the unit of currency in China. In March 2021, one yuan is about US $0.154.

joining an agricultural cooperative, but does not directly affect the usage of CFPs (Terza 2016). Following Ma and Abdulai (2016), the regression took the proportion of other family farms' participation in agricultural cooperatives in the studied county as an IV (IV1).

Data source and variable description

The data used for empirical analysis are obtained from a survey by the Ministry of Agriculture and Rural Affairs of China carried from March to April 2016. The survey collects information on household demographic characteristics, production practices, land market participation, application of agricultural chemicals, and agricultural cooperatives' services. After data cleaning by removing samples with missing information, 2012 valid observations were finally used for this study. Because of the lack of net return data due to the new establishment of some family farms or other reasons, some observations were excluded when analyzing the net return per yuan of CFPs.

Table 1 presents the descriptive statistics of the selected variables. It shows that 27.4% of the family farm heads believed that they applied fewer chemical fertilizers than their neighboring farmers, and 31.0% had the same pesticide perception. On average, every yuan input of CFPs brought a net return of 2.23 yuan. Also, 33.9% of the family farms had participated in agricultural cooperatives, and 335 cultivated wheat, rice, and maize as their primary plants. Among these 335 major grain producers, 81.8% had received technology training service or machinery use service, and 49.0% had received cooperatives' sales services.

Concerning the characteristics of farm heads, on average, their age was 52.7 years, education was 9.57 years, and large scale farm management experience was 6.13 years, which indicate that they were not well educated and experienced in farm management. The average farm size is 28.79 ha, and the average price for the rented farmland is 7590.51 yuan/ha. About 22.4% of farms had received a rental subsidy from the government. The family laborers accounted for 75.2% of the total farm labor force; 61.8% of the farms cultivated wheat, rice, and maize as their primary plants, and 59.4% of the farms tested the soil to formulate fertilization. Nevertheless, only 14.8% of the farms had received quality certification for their agri-products.

Empirical results and discussions

Before formally discussing the empirical results, we have conducted a variance inflation factor (VIF) test to check the multicollinearity issues of the variables. The VIF values of explanatory variables in Eqs. (1) and (4) were less than 1.40 and 2.46, and the condition numbers of those variables were 25.97 and 26.81, respectively. The findings indicate that there were no multi-collinearity issues in our estimated models. The significance of residual terms in columns 3–5 of Table 2 suggested that the unobservable factors simultaneously influenced the decision of agricultural cooperative membership and the usage of CFPs. Thus, the 2SRI model was appropriate and had strong explanatory power.

Impact of cooperative membership

Table 2 reports the regression results of Eqs. (1) and (4), which are estimated simultaneously with the 2SRI approach for the impacts of agricultural cooperatives on the usage of CFPs. After controlling the endogeneity, the results showed that joining agricultural cooperatives improved the probability of reducing fertilizers and pesticides by 17.4% and 17.9%, respectively, and increased the net return per yuan cost of CFPs by 0.59 yuan. The above results were all significant at the 10% level. Yuan et al. (2021) found that Internet use helps reduce fertilizer use in China, while Zhao et al. (2021) showed that Internet use helps reduce pesticide use among vegetable farmers in China. This study provides new evidence that agricultural cooperatives can be an efficient institutional arrangement that reduces both pesticide and fertilizer use in China.

The estimates of Eq. (1) by 2SRI approach revealed that education level and farming experience of the farm head, fertilizing based on soil testing, and agri-products quality certification all had positive impacts on farmers' decision to join an agricultural cooperative, while the farm size and the proportion of family labor force had a negative effect. These findings are largely consistent with the existing literature on agricultural cooperatives (e.g., Jitmun et al. 2020; Liu et al. 2019; Ma and Abdulai 2019; Manda et al. 2020; Minah 2021; Mnisi and Alhassan 2021; Su and Cook 2020; Zhang et al. 2020). All of the above variables were statistically significant. The IV1 was positively and statistically significant, indicating that farmers' decision of joining an agricultural cooperative was positively affected by their peers.

Average treatment effect on the treated (ATT)

The regression results of the ESP and ESR models are presented in Table 3. For the sake of brevity, we only present and discuss the ATT results. The results presented in Table 3 showed that the agricultural cooperative members had a significantly higher probability of reducing the usage of fertilizers and pesticides than the non-member farmers and higher application efficacy of CFPs. The estimated ATT results in Table 3 were positively and statistically significant, which confirmed that agricultural cooperatives could help farmer members reduce the overuse of CFPs and improve the utilization efficacy of the agricultural chemicals. Specifically, after

Table 1 Descriptive statistics of variables

Variables	Description	Value	S.D.
Dependent variables			
Fertilizer reduction	Whether the farm has lowered the usage of chemical fertilizers per mu[1] than surrounding farms? (Reported by farm head): 0=no; 1=yes	0.274	0.446
Pesticide reduction	Whether the farm has lowered the usage of pesticides per mu than surrounding farms? (Reported by farm head): 0=no; 1=yes	0.310	0.462
Net return per yuan CFPs	Net return per yuan cost of CFPs (yuan)	2.234	4.983
Independent variables			
Membership	Cooperative membership: 0=no; 1=yes	0.339	0.473
Production services	Has the farm used the technology service or machinery service provided by cooperatives in the last year? (Among the major grain producer members): 0=no; 1=yes	0.818	0.386
Marketing services	Has the farm used the agri-products sales services provided by the cooperatives in the last year? (Among the major grain producer members): 0=no; 1=yes	0.490	0.501
Control variables			
Age	Age of farm head (year)	52.706	132.236
Education	Farm head's education years (18= master's degree; 16= bachelor's degree; 14= college degree; 11= high school/professional high school diploma; 8= middle school diploma; 5= elementary school; 0= illiterate)	9.567	2.361
Year	Farm head's years of large scale farm management	6.132	4.547
Size	Area of land operated by farms (hectare)	28.788	67.589
Rent	The average rent of farmland (yuan/hectare)	7590.510	4909.808
Subsidy	Whether the farm has received a rental subsidy from the government? 0=no; 1=yes	0.224	0.417
Labor	The proportion of family labors in the total farm labor force	0.752	0.989
Grain	The proportion of the sown area of wheat, corn, and rice in 2015	0.618	0.428
Soil	Whether the farm tested soil for formulated fertilization in 2015? 0=no; 1=yes	0.594	0.491
Certification	Whether the agricultural food products have ever been certificated "pollution-free agri-products", "green foods", "organic products" or "geographical indications of agri-products"? 0=no; 1=yes	0.148	0.355
Typology	The main type of land typology in the farm: 1= plain; 2=hills; 3= mountain land	1.436	0.715
Cropping	How many seasons do the farmlands plant? (Calculation based on the areas of the biggest plot of land)	1.417	0.690

[1] The mu is a common unit of land area in China. One mu is about 0.067 hectare

Table 2 Impact of cooperative membership on the usage of CFPs: 2SRI model estimations

	Cooperative membership	Fertilizer reduction	Pesticide reduction	Net return per yuan CFPs
Membership		0.174** (0.073)	0.179** (0.071)	0.586** (0.343)
Age	0.004 (0.028)	0.022 (0.029)	0.030 (0.031)	0.037 (0.054)
Education	0.056* (0.032)	0.097*** (0.034)	0.036 (0.033)	−0.155*** (0.084)
Year	0.020*** (0.007)	0.013* (0.007)	0.010 (0.007)	0.063* (0.022)
Size	−0.411*** (0.122)	−0.348*** (0.132)	−0.388*** (0.131)	−0.458*** (0.419)
Rent	0.091 (0.077)	0.311*** (0.082)	0.143* (0.083)	0.038*** (0.186)
Subsidy	0.155** (0.066)	0.470*** (0.072)	0.370*** (0.071)	−0.380*** (0.297)
Labor	0.485*** (0.092)	0.107 (0.111)	−0.070 (0.112)	0.756 (0.440)
Grain	−0.059 (0.049)	0.148*** (0.049)	0.129*** (0.049)	−0.316*** (0.249)
Soil	0.092*** (0.033)	−0.077** (0.035)	−0.013 (0.036)	−0.648** (0.218)
Certification	0.008 (0.018)	−0.030* (0.018)	−0.030* (0.018)	−0.349* (0.268)
Typology	−0.115 (0.085)	−0.280*** (0.088)	−0.344*** (0.088)	0.942***(0.559)
Cropping	−0.060 (0.052)	0.215*** (0.053)	0.259*** (0.055)	−0.448*** (0.185)
Residual		0.734*** (0.235)	0.991*** (0.234)	−0.354*** (0.882)
IV1	2.130*** (0.160)			
Constant term	−1.271*** (0.250)	−1.066*** (0.257)	−1.034*** (0.256)	7.410*** (3.107)
Log-pseudo likelihood	−1084.815	−1044.589	−1115.657	−5755.018
Observations	2012	2012	2012	1917

Asymptotically correct standard errors (ACSE) are in in parentheses

***, **, and * represent the 1%, 5%, and 10% significance levels, respectively. To eliminate the dimension, this study has standardized the variables of age and education, which applies to all the following analyses

joining an agricultural cooperative, the possibility to reduce the usage of fertilizers and pesticides increased by 30.1% and 35.9%, respectively, and the net return per yuan of CFPs increased by 7.49 yuan. In conclusion, agricultural cooperatives had a stable and reliable influence on reducing the consumption of CFPs and increasing the application efficacy of CFPs.

Mechanism analysis

We have demonstrated that agricultural cooperatives effectively help their members reduce the usage of CFPs. To further explore how they did it, we focused our analysis exclusively on the grain producers because the grain and other crops were different in production, marketing, and application of CFPs. Very little literature studied the grain producers. Three hundred thirty-five major grain producers had used the services (including production services and marketing services) provided by agricultural cooperatives. Since the choice to use the agricultural cooperative services was an endogenous variable, we chose "Demonstration farm" as an IV (IV2) for this analysis. Demonstration farms were exemplary family farms with exceptional financial performance, farming practice, or many other aspects, awarded by Chinese governments at both regional and national levels. Because the awards reflected the relationship between the recipient farms and governments, and the government greatly influenced the development of agricultural cooperatives in China, demonstration farms are more likely to join an agricultural cooperative than

Table 3 Results of the robustness check

	ESP model			ESR model	
	ATT	*t* value		ATT	*t* value
Fertilizer reduction	0.301*** (0.005)	55.083	Net return per yuan CFPs	7.490*** (0.034)	222.829
Pesticide reduction	0.359*** (0.005)	78.286			

Standard errors are in parentheses

***1% significance level

Table 4 Impacts of using cooperative production services on the usage of CFPs: 2SRI model estimations

	Production services use	Fertilizer reduction	Pesticide reduction	Net return per yuan CFPs
Production services		0.476*** (0.241)	0.693*** (0.244)	0.579*** (0.337)
Age	0.105*** (0.039)	0.020 (0.075)	0.693*** (0.244)	0.203 (0.203)
Education	0.029 (0.088)	0.016 (0.163)	0.032 (0.069)	0.119 (0.140)
Year	−0.016 (0.015)	0.030 (0.028)	−0.013 (0.149)	−0.012 (0.028)
Size	−0.208 (0.312)	−0.145 (0.550)	0.029 (0.027)	−0.173 (0.597)
Rent	−0.008 (0.217)	0.294 (0.353)	−0.097 (0.510)	0.501 (0.341)
Subsidy	0.187 (0.201)	−0.003 (0.380)	−0.036 (0.330)	−0.300 (0.396)
Labor	−0.586*** (0.196)	0.962* (0.514)	−0.120 (0.350)	−0.172* (0.501)
Grain	−0.07 (0.173)	0.543 (0.305)	0.809*(0.473)	0.120 (0.375)
Soil	0.057 (0.116)	−0.077 (0.199)	0.375 (0.283)	−0.715 (0.191)
Certification	0.068 (0.075)	−0.135 (0.173)	0.027 (0.183)	−0.285 (0.283)
Typology	0.058 (0.407)	−1.198 (0.674)	−0.187 (0.160)	−0.061 (0.680)
Cropping	−0.078 (0.212)	0.649*** (0.331)	−0.507 (0.621)	−1.281*** (0.314)
Residual		6.094** (2.430)	0.860*** (0.309)	−4.715** (2.718)
IV2	0.268***(0.103)			
Constant term	0.458(0.856)	−5.55** (2.256)	−5.424** (2.100)	12.559** (3.027)
Log-pseudo likelihood	−144.740	−174.597	−182.525	−705.447
Observations	335	335	335	330

Asymptotically correct standard errors (ACSE) are in parentheses
***, **, and * represent the 1%, 5%, and 10% significance levels, respectively

Table 5 Impacts of using cooperative marketing services on the usage of CFPs: 2SRI model estimation

	Marketing services use	Fertilizer reduction	Pesticide reduction	Net return per yuan CFPs
Marketing services		0.170 (0.165)	0.464*** (0.164)	0.041 (0.239)
Age	0.171** (0.075)	−0.017 (0.087)	−0.010 (0.081)	0.081 (0.184)
Education	0.190** (0.078)	−0.058 (0.142)	−0.099 (0.131)	−0.072 (0.187)
Year	0.014 (0.015)	−0.017 (0.023)	−0.015 (0.022)	−0.005 (0.026)
Size	−0.310 (0.310)	−0.407 (0.451)	−0.340 (0.434)	0.254 (0.556)
Rent	−0.212 (0.184)	0.335 (0.281)	0.024 (0.262)	0.748** (0.332)
Subsidy	0.026 (0.178)	0.388 (0.258)	0.228 (0.240)	−0.482 (0.355)
Labor	−0.592*** (0.186)	0.630 (0.400)	0.526 (0.366)	0.790 (0.611)
Grain	0.103 (0.175)	0.223 (0.252)	0.066 (0.237)	−0.014 (0.444)
Soil	0.011 (0.099)	0.102(0.140)	0.197 (0.134)	−0.787*** (0.179)
Certification	0.098 (0.096)	−0.163(0.127)	−0.216* (0.119)	−0.462 (0.313)
Typology	−0.138 (0.344)	−0.881* (0.512)	−0.184 (0.470)	−0.169 (0.619)
Cropping	−0.139 (0.172)	0.815*** (0.259)	1.028*** (0.243)	−1.240*** (0.314)
Residual		2.712** (1.331)	2.330* (1.241)	1.523 (2.033)
IV3	−0.004**(0.002)			
IV4	0.001**(0.0004)			
Constant term	−0.351 (1.109)	−1.739* (1.186)	−1.982* (1.117)	9.831***(2.630)
Log-pseudo likelihood	−206.746	−183.430	−189.145	−708.356
Observations	335	335	335	330

Asymptotically correct standard errors (ACSE) are in parentheses
***, **, and * represent the 1%, 5%, and 10% significance levels, respectively

their peers due to their close ties with the governments. Moreover, the demonstration farms also can affect other farmers' choices to join an agricultural cooperative and use its services, but not the usage of CFPs. Thus, the demonstration farm met the requirement of a valid IV. The distance to the markets may affect farmers' marketing decisions but not their usage of CFPs. Following Hall and Jones (1999) and Cawley et al. (2018), we used the distance from the farm to the city hall (IV3) and farm to the provincial capital (IV4) as the IVs of choice of selling to agricultural cooperatives. According to whether the farms used the production services or marketing services provided by agricultural cooperatives, we estimated the impact of cooperative membership on the usage of CFPs by the 2SRI approach. The results are shown in Tables 4 and 5.

The estimated coefficients in columns 3, 4, and 5 of Table 4 indicated that after controlling for other variables, using the production services provided by agricultural cooperatives increased the probability of reducing the consumptions of fertilizers and pesticides by 69.3% and 47.6%, respectively, and increased the net return per yuan cost of CFPs by 0.58 yuan. Therefore, the hypothesis of H1 has been verified. Besides, compared with the coefficients of membership in Table 2, which did not differentiate the farms using the production services from those not, cooperative production services had a prominently positive effect on reducing the consumption of CFPs.

The marketing services' coefficient in column 4 of Table 5 was significant at the 1% level, which indicated that using cooperative marketing services decreased the application of pesticides significantly. The hypothesis of H2 was supported. Nevertheless, the marketing services had no significant impacts on the consumption of chemical fertilizers and the net return per yuan CFPs.

In conclusion, agricultural cooperatives made their farmer members lower the usage of CFPs by providing services. Production services had reduced the usage of CFPs and increased the application efficacy of CFPs, while marketing services had significantly decreased pesticide usage.

Conclusions and policy implications

This study investigated whether agricultural cooperatives can serve as an institutional arrangement that helps reduce the consumption of CFPs. By employing the 2SRI approach and the ATT estimators based on the ESP and ESR models, we quantified the impacts of the agricultural cooperative membership on the consumption of CFPs. We analyzed the mechanisms using the family farm data from the Ministry of Agriculture and Rural Affairs of China.

Our empirical results showed that agricultural cooperatives increase the possibilities of reducing fertilizers and pesticides' consumption. After controlling the endogeneity, the results showed that joining agricultural cooperatives improved the probability of reducing fertilizers and pesticides by 17.4% and 17.9%, respectively, and increased the net return per yuan cost of CFPs by 0.59 yuan. Agricultural cooperative production services reduced the usage of fertilizers and pesticides, while cooperative marketing services only significantly lowered the use of pesticides.

Our findings have important policy implications. Firstly, since agricultural cooperatives can play essential roles in protecting the agroecological environment, improving the quality and safety of agricultural food products, disseminating modern agricultural technology, and promoting agricultural production mode transformation, it is necessary to provide policy supports to promote these relative roles of agricultural cooperatives. Secondly, it is vital to offer agricultural production technology and pesticide residues test to agricultural cooperatives, support cooperatives to provide agricultural production services and marketing services for family farms, and strengthen the role of cooperatives in managing the process of agricultural production and supervising the quality of agri-products. Thirdly, it is essential to encourage more family farms to join agricultural cooperatives, especially larger-scale and skilled family farms and make them the backbone of the agricultural cooperatives; it is also critical to assist cooperatives in guiding family farms to use agricultural inputs effectively, especially CFPs, and achieve the coordinated development between agricultural cooperatives and family farms. Lastly, the government should ensure that the agricultural cooperatives can provide farmer members with technical training to use CFPs properly and make the agricultural cooperatives aware of the importance of monitoring the agricultural chemicals application and quality control.

This study is subject to a limitation. We have used farmers' perceptions to measure pesticide use reduction and fertilizer use reduction because we are lack of detailed quantitative data of these two inputs. When required data are available, it might be an interesting direction for future studies to look at how agricultural cooperatives affect the quantities of pesticide and fertilizer use in agricultural production.

Author contribution All authors contributed to the study conception and design. Tongshan Liu made substantial contributions to the conception or design of the work. The draft was mainly written by Tongshan Liu. Gang Wu performed the literature search and data analysis. All authors read and approved the final manuscript.

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Data availability The data that support the findings of this study are available from the leading author, Tongshan Liu, upon reasonable request.

Declarations

Ethics approval and consent to participate Not applicable

Consent for publication Not applicable

Competing interests The authors declare no competing interests.

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