Land tenure stability and adoption intensity of sustainable agricultural practices: Evidence from banana farmers in China

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1. Introduction

Inappropriate agricultural practices may cause a range of environmental problems such as air pollution, water shortage and land deterioration, which in turn pose challenges to land productivity, sustainable agriculture development and even human health (Atreya et al., 2012; Midingoyi et al., 2019; Ma and Wang, 2020). It is imperative to develop a sustainable agriculture for alleviating the adverse effects. The sustainable agricultural practices (SAPs) are widely deemed as an important role in reducing carbon emissions and improving the sustainability of farmland (FAO, 2019), particularly in many developing countries. The SAPs are a set of agricultural technologies featured by conserving resources and environment friendly and thus contributing to the sustainable agriculture. As mentioned in existing studies, SAPs include drip fertigation system, integrated pest management (IPM) technology, conservation tillage and fallow, intercropping, crop rotation, use of farmyard manure, etc. (Kassie et al., 2013; Ndiritu et al., 2014; Zeweld et al., 2017; Tambo et al., 2018; Midingoyi et al., 2019; Ma and Wang, 2020). The function of SAPs is to reduce the adverse effect of agricultural activities to environment and enhance economic benefits of farms (Teklewold, 2013; Kassie, 2015a; Manda, 2016; Van Vugt et al., 2017; Adane et al., 2019; Gokul et al., 2019; Ma and Wang; 2020). For example, in the case of Ghana, farmers' adoption of water and conservation technologies increased rice yields and economic returns (Abdulai and Huffman, 2014). Also, Midingoyi et al. (2019) found that the adoption of IPM technology significantly increased mango yields and net revenues, with lower pesticide use which better protect the environment and human health. Despite the environmental and economic advantages brought by the SAPs, they are rarely adopted in developing countries (Adolwa et al., 2019; Midingoyi et al., 2019; Yang et al., 2020). Therefore, the most important step is to identify the obstacles in farmers' adoption of SAPs, and formulate more effective policies to facilitate the spread of SAPs in these regions.

The secure land property rights are considered as an incentive for farmers to invest on farmland (Aha and Ayitey, 2017), and also affect their adoption of innovative agricultural technologies (Rasul et al., 2004; Abdulai, 2011; Kirtti, 2018; Lovo, 2016; Zeng et al., 2018). In the context of unstable property rights of land resources, rational farmers may reduce their willingness to invest in farmland (Coase, 1960; Alchian and Demsetz, 1972), as the property rights are the important foundation to connect human's actions with their expected returns (Alchian and Demsetz, 1973). Farmers may actively invest on farmland only when they can make sure of economic returns (Besley, 1995; Lyu et al., 2019). For example, Nkomoki et al. (2018) found that land property rights played a positive role in farmers' adoption of a wide range of sustainable agricultural practices. Similarly, Tschopp et al. (2020) argued that secure land property rights increased the likelihood of adoption of sustainable agricultural practices in Northern Argentina. Muraoka et al. (2018) insisted that farmers' decision to invest on farmland was closely correlated with land tenure stability, especially for the investment which was paid off in a longer term. Nevertheless, other researchers hold an opposite viewpoint. Brasselle et al. (2002) argued that the impact of land tenure stability on investment of agricultural technologies was not found. In the case of Pakistan, both sharecropping and cash rental would suppress investments on agricultural conservation, while long-term contracts would alleviate the adverse effect (Jacoby and Mansuri, 2008). Previous studies also paid much attention to the less developed countries where an insecure land property rights and unstable land rental market exist (Heidi, 2019). The establishment of formal rural land transfer market seems to be beneficial to households with abundant labor endowments (Deininger and Jin, 2005), because it can transfer farmland from inefficient households to more efficient ones. Therefore, farmland can be better allocated among farmers, and then it may enhance the diffusion of SAPs in developing regions.

China is a typical case of land system based on collective ownership in developing countries. The Household Responsibility System (HRS) was created to separate the land ownership and land operational rights. Farmers are authorized to possess land operational rights based on the contract signed with the local government, and the local government has the right to reassign the farmland when the land contract is due. Farmers have had the legal right to transfer the farmland in land rental market since the Rural Land Contracting Law of China was released in 2003 (Chari et al., 2017). The ratio of farmland rental in rural China increased from 4.44% in 2002 (Wu, 2003) to 16.2% in 2011 (Wu, 2011), then 28.8% in 2014 (Han, 2014). Land transfer market can reduce the land fragmentation of smallholder farmers in China and may lead to more technological investments in agriculture production (Tan et al., 2006), thus achieving a higher crop production (Feng et al., 2010). However, the evidence from parcel-level analysis revealed that land productivity and investments on rented farmland were still lower than that on own farmland (Muraoka et al., 2018). More importantly, SAPs are a group of agricultural technologies that help farmers transfer to a more sustainable use of agricultural resources. The economic return of investment in SAPs usually lags in following years. Farmers' willingness to adopt SAPs may be weakened by unstable land-use rights if they rented farmland from others. The correlation between land tenure stability and farmers' adoption intensity of SAPs is uncertain and deserves a further discussion.

This paper takes a case study of banana production in the context of China's rural land system and attempts to contribute to the literature by investigating the impact of land tenure stability on farmers' adoption intensity of SAPs from three aspects. First, despite previous literature has explored the impact of land property rights on farmers' adoption of resource-conservation technology, they focused on only one innovative technology (e.g. Kirtti, 2018; Zeng et al., 2018; Gao et al., 2018). This study considers a group of SAPs and focus more on farmers' adoption intensity of SAPs. Generally, farmers use multiple SAPs in their farming practices, and the combination of these agricultural technologies is likely to have more robust effect on land productivity than a single one. For example, the studies in Ethiopia and Malawi indicated that a combined of different sustainable agricultural technologies could lead to a higher maize net income than single agricultural technology adoption (Teklewold et al., 2013; Kassie et al., 2014). Evidence also shows that the combination of agricultural technologies can increase farmers' income and then stimulate their adoption of agricultural technologies (Yu et al., 2012). The present study is designed to examine if land tenure stability affects farmers' adoption intensity of SAPs in developing regions. Second, the impact of land tenure stability on farmers' adoption intensity of SAPs can be incorrectly estimated if using simple regression models, because farmers' adoption decisions are more prone to be self-selection choices rather than random ones in reality (Ma and Abdulai, 2016; Ma et al., 2018; Deng et al., 2019). This study employs the endogenous switching regression (ESR) model to eliminate the self-selection bias of sample farmers. It can simultaneously give a consideration to both observed and unobserved factors that may affect farmers' decisions, thus the estimation results are more reliable (Ma and Abdulai, 2016; Ma et al., 2018; Tesfaye and Tirivayi, 2018; Deng et al., 2019). Third, the heterogeneous effect of land tenure stability on farmers' adoption intensity of SAPs is explored in different groups of farmers divided based on their farm sizes and regions. It is rarely discussed in previous studies.

The remainder of this study is arranged as follows: Section 2 presents a theoretical framework and empirical strategies. Section 3 introduces the data and variables used in this study. The descriptive statistics, empirical results and heterogeneity analysis are given in Section 4. Section 5 discusses the association between farmers' adoption of SAPs and land productivity. The last section includes conclusion, limitations and possible further studies.

2. Analytical Framework and Empirical Strategy

2.1 Analytical Framework

It is uncertain that whether farmers would use SAPs when they cultivate a high proportion of rented land resources due to the absence of land tenure stability. Following previous studies, a farmer's decision on renting in farmland can be modeled in a random utility framework (Becerril and Abdulai, 2010; Kassie et al., 2015b; Adane, 2019). We assume that R_i^* is the utility difference between farmers who mainly cultivate their own farmland* (U_{iO}) and those who mainly cultivate rented farmland (U_{iR}), so the farmer i would choose to cultivate on their own farmland if $R_i^*= U_{iO}$-U_{iR} > 0. However, the utility difference of these two groups cannot be observed directly. R_i^* can be obtained from following equation:

$$R_i^* = \alpha_1 Z_i + \mu_1 \text{ with } R_i = \begin{cases} 1 & if\ R_i^* > 0 \\ 0 & otherwise \end{cases} \quad (1)$$

where R_i^* is the probability of farmer i mainly cultivates owned farmland, and it determined by the observable variable R_i which represents farmer i's actual choice of mainly cultivating their own farmland. R_i equals 1 if the rented farmland farmer i cultivates is less than his/her own farmland, and 0 otherwise; Z_i is a vector of variables that represent socio-economic characteristics of the farmer i; α_1 is a vector of parameters to be estimated; and μ_1 is an error term.

Due to unstable land-use rights, the choices of using SAPs in farming practices between farmers who cultivate more rented farmland and those who mainly cultivate own farmland may be different. We assume that farmers' adoption intensity of SAPs is a function relating to farmers' land rental behavior (R) and a vector of control variables (X), and the regression equation can be constructed as follows:

$$A_i = \gamma X_i + \omega R_i + \mu_2 \quad (2)$$

where A_i represents the farmer i's adoption intensity of SAPs, γ and ω are parameters to be estimated, and μ_2 is an error term. ω measures the impact of land tenure stability on farmers' adoption intensity of SAPs in Equation (2). Only if the sample farmers are randomly assigned to the treated group (i.e. farmers who cultivate more own farmland) and the control group (i.e. farmers who cultivate more rented farmland), it can reach an unbiased estimation of ω. In fact, a farmer's decision on cultivating their own farmland is not a random but voluntary choice, and it can be affected by observable variables (e.g., access to loan service) and unobservable

* "Their own farmland" means that farmers hold a legal land contract with local government and have full land operational rights for agricultural production. The contract usually lasts for 30 years despite the land is still collective owned.

characteristics (e.g., farmers' inherent ability), which may produce the sampling bias and incorrect estimation of the effect of land tenure stability on farmer's adoption intensity of SAPs. Existing studies showed that the PSM strategy can be used to solve the biased estimation problems (Shiferaw, 2014; Fentie and Beyene, 2019). However, it ignores the possible unobserved factors that may also influence farmers' decision (Chen, 2014; Liu, 2017; Jeanne et al., 2017; Adane et al., 2019). And the estimation of PSM method is unbiased only if the treatment model has been correctly specified (Ma and Wang, 2020; Adane et al., 2019). This study employs the endogenous switching regression (ESR) model to control both the observed and unobserved factors between the treated group and the control group of farmers at the same time, in order to obtain more reliable estimation results. A detailed estimation strategy is given in the following subsection.

2.2 Empirical Strategy

The ESR model is used to estimate the effect of land tenure stability on farmers' adoption intensity of SAPs. First, this model takes both observed and unobserved factors into account whenever farmers mainly cultivate rented farmland or not. Second, it simultaneously estimates the outcome equation (i.e. the farmers' adoption intensity of SAPs) of both the treated and control group, thus it can better recognize the role of control variables. Third, using full information maximum likelihood estimator in ESR model can better avoid the problem of missing variables (Lokshin & Sajaia, 2004; Liu, 2017).

The ESR model is a two-stage estimation strategy. In this study, the first stage is to estimate a farmer's decision of renting farmland that exceeds his/her own farmland in Equation (1). In the second stage, the full information maximum likelihood estimator is used to estimate the correlations between farmers' adoption intensity of SAPs and socioeconomic characteristics (individual-level and household-level) under two different regimes:

$$\text{Regime 1: } A_{iO} = \beta_1 X_{iO} + \varepsilon_{iO} \quad \text{if Land tenure stability = 1} \tag{2a}$$

$$\text{Regime 2: } A_{iR} = \beta_2 X_{iR} + \varepsilon_{iR} \quad \text{if Land tenure stability = 0} \tag{2b}$$

where A_{iO} and A_{iR} represents farmers' adoption intensity of SAPs when they cultivate more owned farmland and when they mainly cultivate rented farmland, respectively; X_{iO} and X_{iR} are individual-level and household-level characteristics of farmers; β_1 and β_2 are parameters to be estimated; ε_{iO} and ε_{iR} are error terms.

As farmers' decision of cultivating banana mainly on rented farmland can be endogenous, the correlation between error terms ε_{iO} and ε_{iR} based on the sample selection criteria has a non-zero expected value (Abdulai & Huffman, 2014). So, the parameters (β_1 and β_2) of OLS estimation may produce sample selection bias. It is also called as the problem of missing variables (Lee, 1978). Assuming that these three error terms μ_1, ε_{iO} and ε_{iR} have a trivariate normal distribution with zero mean and the variance-covariance structure is:

$$\text{cov}(\mu_1, \varepsilon_{iO}, \varepsilon_{iR}) = \begin{bmatrix} \sigma_\mu^2 & \sigma_{O\mu} & \sigma_{R\mu} \\ \sigma_{O\mu} & \sigma_O^2 & \sigma_{RO} \\ \sigma_{R\mu} & \sigma_{RO} & \sigma_R^2 \end{bmatrix} \tag{3}$$

where the σ_μ^2, σ_O^2 and σ_R^2 are the variances of error terms (μ_1, ε_{iO} and ε_{iR}); and $\sigma_{O\mu}$ denotes the covariance of μ_1 and ε_{iO}, and the $\sigma_{R\mu}$ denotes the covariance of μ_1 and ε_{iR}. We also define the ρ as correlations between error terms, for farmers who mainly cultivate rented farmland and those who mainly cultivate own farmland, and it can be described as $\rho_{O\mu} = corr(\varepsilon_{iO}, \mu_1)$ and $\rho_{R\mu} = corr(\varepsilon_{iR}, \mu_1)$. Alternatively, $\rho_{O\mu}$ and $\rho_{R\mu}$ can be given as $\rho_{O\mu} = \sigma_{O\mu}/\sigma_O\sigma_\mu$ and $\rho_{R\mu} = \sigma_{R\mu}/\sigma_R\sigma_\mu$. However, A_{iO} and A_{iR} do not occur at the same time, so the covariance between ε_{iO} and ε_{iR} is uncertain. Based on this assumption, the expected values of ε_{iO} and ε_{iR} can be expressed as:

$$E(\varepsilon_{iO} \mid O_i = 1) = \sigma_{O\mu}\frac{\vartheta(\gamma Z_i/\sigma)}{\theta(\gamma Z_i/\sigma)} \equiv \sigma_{O\mu}\lambda_O \quad (4)$$

$$E(\varepsilon_{iR} \mid R_i = 0) = \sigma_{R\mu}\frac{-\vartheta(\gamma Z_i/\sigma)}{1-\theta(\gamma Z_i/\sigma)} \equiv \sigma_{R\mu}\lambda_R \quad (5)$$

where $\vartheta(.)$ denotes the standard normal probability density function, $\theta(.)$ denotes the standard normal cumulative density function, and λ_O and λ_R represent inverse Mills ratio, specifically $\lambda_O = \frac{\vartheta(\gamma Z_i/\sigma)}{\theta(\gamma Z_i/\sigma)}$ and $\lambda_R = \frac{-\vartheta(\gamma Z_i/\sigma)}{1-\theta(\gamma Z_i/\sigma)}$. If we can find an instrumental variable that is exogenous, λ_O and λ_R can be obtained from the first stage and included in Equation (2a) and (2b) (Adane et al., 2019; Fuglie & Bosch, 1995). In doing so, at least one variable which can affect farmers' decision of mainly cultivating their own farmland but cannot affect their adoption intensity of SAPs should be included in the selection equation to make the model recognizable (Abdulai & Huffman, 2014; Adane et al., 2019). Considering that farmers' decision of cultivating banana mainly on their own farmland could be closely associated with farmers' abandoned farmland, thus we use the variable of *Abandon farmland* as the instrumental variable in this study. The regression results also show that *Abandon farmland* has no statistically significant effect on *Adoption intensity* but significantly affects *Land tenure stability*. Therefore, the instrumental variable *Abandon farmland* in our model is valid.

In order to examine the effect of land tenure stability on farmers' adoption intensity of SAPs, we use the estimated coefficients of ESR model to calculate the average treatment effect which indicates the difference between the expected values of observed and counterfactual scenarios. In this study, we estimated the average treatment effect on the treated group (ATT) and it is specified as the difference between Equation (6) and (7):

$$E(A_{iO} \mid O_i = 1) = \beta_1 X_{iO} + \sigma_{O\mu}\lambda_O \quad (6)$$

$$E(A_{iR} \mid O_i = 1) = \beta_2 X_{iO} + \sigma_{R\mu}\lambda_O \quad (7)$$

Following previous studies (e.g., Lokshin and Sajaia, 2004; Gokul et al., 2019), the ATT can be calculated by Equation (8):

$$ATT = E(A_{iO} \mid O_i = 1) - E(A_{iR} \mid O_i = 1) = (\beta_1 - \beta_2)X_{iO} + (\sigma_{O\mu} - \sigma_{R\mu})\lambda_O \quad (8)$$

In Equation (6), (7) and (8), $E(A_{iR} \mid O_i = 1)$ denotes the counterfactual expected value of farmers' adoption intensity of SAPs, and $E(A_{iO} \mid O_i = 1)$ denotes the actual expected value of farmers' adoption intensity of SAPs. ATT can be used to eliminate the estimation bias caused by observed and unobserved factors and examine the overall effect of land tenure stability on farmers' adoption intensity of SAPs.

3. Data

3.1. Data collection

The data used in this study was from the field survey of banana growers conducted by our research team in South China from July to October 2019. As shown in Table 1, the samples were distributed evenly in three provinces including Guangdong, Hainan and Yunnan. The fourth column shows farmers' adoption intensity of SAPs in each province. The stratified random sampling technique is used to collect the data. First, the three provinces were purposely chosen because they are main banana producers in China. In 2018, the banana acreage in these three provinces accounted for 67.75% of the total banana acreage in China (National Banana Industry

Technology System of China, 2019). Then we randomly selected five counties from Guangdong province, three counties from Hainan province and six counties from Yunnan province (See Figure.1). From each county, we randomly selected several villages, and then around 20 farmers were randomly selected in each village. Finally, 629 valid respondents were obtained. The questionnaire consists of three aspects including farmer's individual characteristics, household characteristics, and agricultural production.

Table 1 Description of sample distribution

Province	Number of observations	Percentage (%)
Guangdong	213	33.86
Hainan	230	36.57
Yunnan	186	29.57

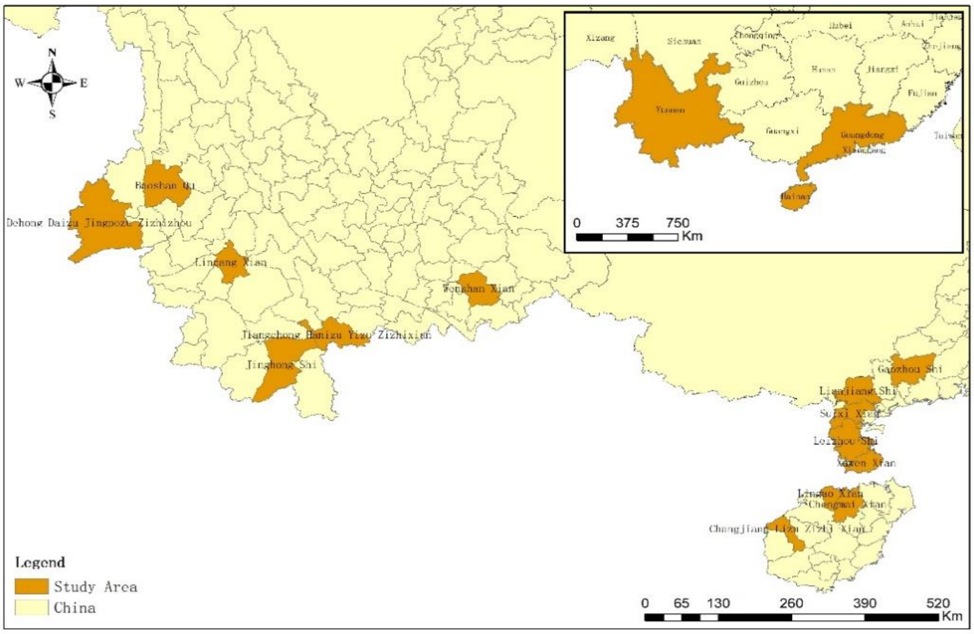


Figure 1 Map of study area

3.2. Variables

The explained variable in the ESR model is *Adoption intensity*. It is defined as the numbers of SAPs used by farmers in banana cultivation. The SAPs for banana cultivation in China mainly include drip fertigation, fallow, crop rotation and farmyard manure. We prepared a list of these technologies and asked farmers to choose ones they used during banana production in 2018. If the farmer adopted a given technology, it is denoted as 1; otherwise 0. The count of SAPs ticked by the farmer is the value of *Adoption intensity*, ranging from 0 to 4.

Land tenure stability is the core explanatory variable in the model. If the area of rented farmland accounts for less than 50 percent of farmer's total cultivated area for banana production, the value of *Land tenure stability* is given as 1; otherwise 0. To solve the endogeneity problem caused by farmers' self-selection bias, we use *Abandon farmland* as the instrumental variable in the model. It equals 1 if a farmer has abandoned farmland in 2018; otherwise, it is 0.

Farmers' socioeconomic characteristics are also included as the control variables in the model. Specifically, we include age, gender, education, marriage status, village cadre, farming experience, farm size, household income, risk preference, labor force, loan, cooperative membership, training, soil degradation, personality, and social ties. In addition, region dummy variables are considered to explore the possible regional heterogeneity.

Table 2 Definition and measurement of variables

Variable	Definition and measurement	Mean	S.D.
Explanatory variable			
Land tenure stability	=1 if the rented farmland area is less than 50% of the respondent's total cultivated area; otherwise =0	0.68	0.47
Explained variables			
Drip fertigation	=1 if the respondent adopts Drip fertigation in banana production; otherwise =0	0.52	0.50
Fallow	=1 if the respondent lets farmland fallow in banana production; otherwise =0	0.26	0.44
Crop rotation	=1 if the respondent takes crop rotation in banana production; otherwise =0	0.49	0.50
Farmyard manure	=1 if the respondent uses farmyard manure in banana production; otherwise =0	0.69	0.46
Adoption intensity	Numbers of SAPs used in banana cultivation (from 0 to 4)	1.96	1.08
Adoption ratio	The share of SAPs adoption in total SAPs (from 0 to 1)	0.490	0.27
Control Variables			
Age	Age of the respondent	48.31	9.86
Gender	=1 if the respondent is male; otherwise =0	0.83	0.38
Education	Education years of the respondent	8.07	3.15
Marriage status	=1 if the respondent has a spouse; otherwise =0	0.97	0.18
Village cadre	=1 if the respondent is a village cadre; otherwise =0	0.23	0.42
Farming experience	Years of engaging in agricultural activities	25.16	11.74
Farm size	Farm size of banana (mu[a])	29.29	72.76
Household income	Total household income (CNY)	26.93	75.10
Risk preference	=1 if the respondent prefers things with certainty; otherwise =0	0.86	0.34
Labor force	Numbers of family's labor force	2.22	0.96
Loan	=1 if the household has a loan; otherwise =0	0.37	0.48
Cooperative membership	=1 if the respondent joins an agricultural cooperative; otherwise =0	0.22	0.41
Training	=1 if the respondent takes any agricultural training; otherwise=0	0.39	0.49
Soil degradation	=1 if the respondent perceives that soil fertility has deteriorated seriously; otherwise =0	0.31	0.46
Personality	=1 if the respondent self-reported he or she can be the first one to adopt innovations; otherwise =0	0.72	0.45
Social ties	Average degree of the respondent's social ties, including the ties with local government, other farmers, retailers and so on	2.53	0.60
Instrumental Variable			
Abandon farmland	=1 if the respondent has abandoned farmland (excluding land converted from farmland to forest); otherwise =0	0.14	0.34

Notes: a. 1 mu = 1/15 hectare

4. Results

4.1. Descriptive statistics

Table 2 presents the definition and the descriptive statistics of variables used in this study. Nearly two thirds of farmers in our sample planted banana mainly on their own farmland in 2018. The average value of farmers' adoption intensity of SAPs is about 1.96, out of four SAPs. The adoption rates of drip fertigation, crop rotation, and farmyard manure technology are comparatively higher than that of fallow practice among banana farmers. Figure 2 depicts the sample distribution of farmers' adoption intensity of SAPs. It shows that nearly 8% of banana farmers did not adopt any SAPs, while 7.95% used four SAPs in banana production. The majority of them took one to three SAPs, suggesting that these practices have been widely recognized by banana growers.

Table 3 reports the mean differences in farmers' socioeconomic characteristics between two groups. The treated group includes farmers who grow bananas with land tenure stability, and the control group consists of farmers who mainly cultivate rented land. As shown in Table 3, the treated group is systematically different from the control group in some observed aspects. Firstly, the farmers who mainly cultivate their own farmland adopted more SAPs and they are more likely to be a village cadre than the farmers who cultivate more rented farmland. Farmers in the treated group are more willing to adopt an innovation in agricultural production. Farmers in the control group abandon farmland less than farmers in the treated group. Table 3 also shows that farmers in the control group have a higher education and hold more farm size for banana cultivation and higher household income. And they grant more loans and share a wider range of social networks. Also, they participate more actively in training activities. From the descriptive results of mean differences in Table 3, it is believed that the land tenure stability is an important factor for understanding farmers' adoption intensity of SAPs in banana production. The preliminary analysis also suggests that unstable land-use rights may decrease farmers' adoption intensity of SAPs. Thus, a further econometric analysis is required to estimate the effect of land tenure stability on farmers' adoption intensity of SAPs.

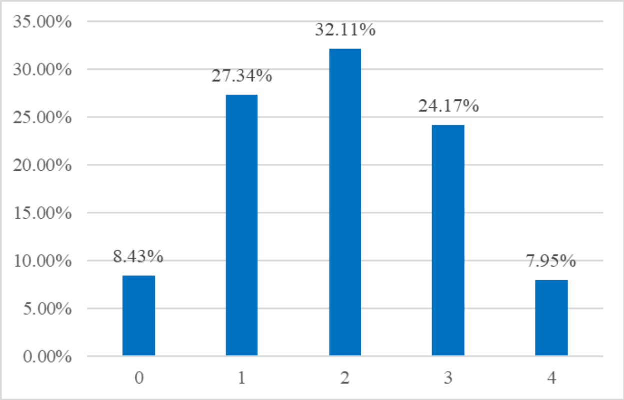


Figure 2 Sample distribution of farmers' adoption intensity of SAPs

Table 3 Difference of characteristics between treated group and control group

Variable	Control group	Treated group	Mean Diff.
Drip fertigation	0.53	0.51	-0.02
	(0.04)	(0.02)	
Fallow	0.20	0.29	0.09**
	(0.03)	(0.02)	
Crop rotation	0.47	0.51	0.04
	(0.04)	(0.02)	
Farmyard manure	0.65	0.70	0.05
	(0.03)	(0.02)	
Adoption intensity	1.84	2.01	0.17*
	(0.08)	(0.05)	
Age	47.55	48.67	1.12
	(0.62)	(0.50)	
Gender	0.80	0.90	0.10***
	(0.02)	(0.02)	
Education	8.66	7.79	-0.87***
	(0.21)	(0.15)	
Marriage status	0.97	0.96	-0.01
	(0.01)	(0.01)	
Village cadre	0.19	0.25	0.06*
	(0.03)	(0.02)	
Farming experience	24.36	25.54	1.18
	(0.78)	(0.58)	
Farm size	68.88	10.28	-58.60***
	(8.17)	(0.70)	
Household income	63.85	9.21	-54.64***
	(8.61)	(0.59)	
Risk preference	0.81	0.89	0.08***
	(0.03)	(0.02)	
Labor force	2.17	2.24	0.07
	(0.07)	(0.05)	
Loan	0.51	0.31	-0.20***
	(0.04)	(0.02)	
Cooperative membership	0.25	0.20	-0.05
	(0.03)	(0.02)	
Training	0.51	0.32	-0.19***
	(0.04)	(0.02)	
Soil degradation	0.29	0.31	0.02
	(0.03)	(0.02)	
Personality	0.67	0.75	0.08**
	(0.03)	(0.02)	
Social ties	2.67	2.47	-0.20***
	(0.04)	(0.03)	
Abandon farmland	0.08	0.17	0.09***
	(0.02)	(0.02)	

Notes: Standard errors are in parentheses, and ***, **, * represent significance level at 1%, 5%, 10%, respectively.

4.2. Estimation results of ESR

Table 4 reports the results about the determinants of farmers' choices to grow banana mainly on their own farmland and its effect on farmers' adoption intensity of SAPs in banana production. The Wald test rejects the null hypothesis that the selection equation and the outcome equation are independent with the significance level at 1%, and LR test is significant at 1% level too. $\rho_{O\mu}$ and $\rho_{R\mu}$, which reflects the correlation between μ_1 and ε_i, are significantly non-zero at 1% level. These results indicate that farmers' decision of cultivating banana mainly on their own farmland is not a random choice, thus the self-selection bias exists. In this scenario, either observed or unobserved factors could affect farmers' behavior regarding their decision of mainly cultivating their own farmland and adoption intensity of SAPs. Therefore, the ESR model is appropriate for this study.

The second column of Table 4 reports the determinants of farmers' decision of cultivating high proportion of their own farmland. Farmers' Marriage status, Household income, Loan and Training negatively and significantly affect Land tenure stability. Specifically, farmers who are in a marriage and possess higher household income are more likely to cultivate banana mainly on rented farmland. Supported by the access to loan, farmers are able to grow more bananas on rented farmland. The similar effect has also found with farmers' participation of agricultural training.

The results in the third and fourth columns of Table 4 suggest that farmers' adoption intensity of SAPs in treated and control groups are obviously affected by different factors. For the control group, *Labor force* shows a negative sign with significance level at 5%, indicating that the family with more labor force has lower tendency to use more SAPs in banana production. This may be because these SAPs also save labor costs to some extent, and it is contrary to the evidence from Zhang et al. (2020). Farmers' personality significantly affects their adoption intensity of SAPs both in treated group and control group with a positive sign, suggesting that more open-minded farmers are more likely to increase adoption intensity of SAPs. In terms of the treated group, a significant and positive correlation between farmers' age and adoption intensity of SAPs is found according to Table 4. It means that the older farmers may adopt more SAPs. Generally, the older farmers are lack of job opportunities in the labor market and can only engage in agricultural activities. These innovative technologies can help them reduce the labor costs of banana production. Thus, older farmers may promote adoption intensity of SAPs. This finding is consistent with Wondimagegn et al. (2018), and they argued that aged farmers were more aware of the potential loss brought by unsustainable agriculture and then would be more active in adoption of advanced technologies. Both *Gender* and *Marriage status* present a significant and negative sign in the treated group. Interestingly, *Farming experience* is significantly and negatively correlated to *Adoption intensity* in banana production. The experienced farmers are less likely to adopt SAPs, the reason may be that they are more confident about their experiences in agriculture production. The variable *Household income* shows a significant and negative sign, indicating that the households of higher income adopt less SAPs. It may be because these farmers are engaged more in off-farm work, and may invest less in agriculture. *Risk preference* is significantly and negatively correlated to *Adoption intensity*. It means farmers who prefer things with certainty are less likely to adopt SAPs. Farmers in the treated group are more self-sufficient farmers, so that most of them may be less willing to take risks. Yet, new agricultural technologies are usually deemed as risks in production by farmers. Farmers who mainly cultivate their own farmland with taking more loans tend to adopt less SAPs. Our field research shows that farmers mainly use the loans for non-agricultural purposes, such as children's education and housing construction.

Table 5 reports the quantitative effect of land tenure stability on farmers' adoption intensity of SAPs. As shown in Table 5, the mean value of farmers' adoption intensity of SAPs in the treated group and control group are 2.01 and 1.43, respectively. And the average treatment effect of *Land tenure stability* on *Adoption intensity* is 0.58 at 1% significance level. Unstable land tenure can reduce farmers' adoption intensity of SAPs by 40.59% compared with the control group. Farmers' adoption of SAPs contributes to the sustainable development of agriculture, but the poor land tenure stability may hinder the diffusion of green technologies and then it may threaten the sustainability of agricultural production.

Table 4 Impacts of land tenure stability on farmers' adoption intensity of SAPs

	Selection	Adoption intensity	
		Control group	Treated group
Age	-0.002	0.013	0.019**
	(0.009)	(0.012)	(0.009)
Gender	-0.235	-0.027	-0.268*
	(0.164)	(0.247)	(0.150)
Education	0.011	-0.026	0.026
	(0.022)	(0.027)	(0.021)
Marriage status	-0.747*	0.404	-0.587*
	(0.400)	(0.446)	(0.326)
Village cadre	0.013	0.075	-0.034
	(0.153)	(0.198)	(0.147)
Farming experience	0.002	-0.009	-0.027***
	(0.008)	(0.009)	(0.008)
Household income	-0.027***	0.001	-0.020***
	(0.003)	(0.001)	(0.005)
Risk preference	0.133	0.020	-0.395**
	(0.177)	(0.194)	(0.181)
Labor force	0.038	-0.181**	0.071
	(0.068)	(0.087)	(0.060)
Loan	-0.462***	0.165	-0.389***
	(0.130)	(0.167)	(0.133)
Cooperative membership	0.257	-0.032	0.046
	(0.162)	(0.181)	(0.154)
Training	-0.257**	-0.128	0.121
	(0.126)	(0.163)	(0.126)
Soil degradation	-0.177	-0.110	0.032
	(0.122)	(0.161)	(0.119)
Personality	0.072	0.508***	0.431***
	(0.136)	(0.173)	(0.129)
Social ties	0.007	-0.102	-0.036
	(0.102)	(0.136)	(0.101)
Abandon land	0.370**		
	(0.169)		
Constant	1.806***	1.285	2.142***
	(0.624)	(0.870)	(0.545)
Ln ($\sigma_{O\mu}$)		0.180***	
		(0.068)	
$\rho_{O\mu}$		1.330***	
		(0.357)	
Ln ($\sigma_{R\mu}$)			0.031
			(0.059)
$\rho_{R\mu}$			-0.374*
			(0.192)
Wald chi2	32.10***		
Log likelihood	-1179.671		
LR test of indep. Eqns.	9.74***		
Observation	629		

Note: Standard errors are in parentheses, and ***, **, * represent significance level at 1%, 5%, 10%, respectively.

Table 5 Average treatment effect of land tenure stability on farmers' adoption intensity of SAPs

Adoption intensity		ATT	t-value	Change (%)
Control group	Treated group			
1.429	2.009	0.580	22.546***	40.59
		(0.026)		

Notes: Standard error is in parentheses, and ***, **, * represent significance level at 1%, 5%, 10%, respectively.

4.3 Heterogeneity

To explore the heterogeneous effect among farmers, this study divided the sample farmers into different groups based on farm size and province, respectively. The average treatment effect of *Land tenure stability* on *Adoption intensity* is estimated in different groups of farmers. The results are presented in Table 6 and Table 7. Because the median size of farmers' banana cultivated area is 10 mu, the sample farmers are divided into two groups. Then we estimate the average treatment effect of land tenure stability on farmers' adoption intensity in different groups. The value of ATT in Table 6 shows that *Land tenure stability* affects *Adoption intensity* significantly and positively in the group with a larger farm, while in the group with a smaller farm, we find that it shows a significant negative sign. The results also show that land tenure stability may increase farmers' adoption intensity of SAPs by 45.81% in the group with larger farm size, and it may decrease farmers' adoption intensity of SAPs by 9.50% in the group with smaller farm size. Figure 3 shows that the banana farmers who adopt two SAPs account for the largest proportion (34.48%) in the group with a smaller farm. In contrast, 30.96% of the farmers with a larger farm adopt only one SAP in banana production. Farmers with a larger farm size may take more risks than those who run smaller farms, so they would be more concerned about the economic benefits in the short term and care less about the sustainability of agricultural production.

Table 7 reports the estimated results of the average treatment effect of *Land tenure stability* on *Adoption intensity* within different provinces. In the ESR model, we add binary variables in indicate the provinces farmers are located in. The estimated results show that farmers' adoption intensity of SAPs in the treated group (2.01) is higher than those in the control group (1.41), and land tenure stability may increase farmers' adoption intensity of SAPs by 42.99% in Guangdong Province. In Hainan Province, land tenure stability may increase farmers' adoption intensity of SAPs by 18.91%. The average treatment effect of farmers' adoption intensity of SAPs between farmers in the treated group and the control group holds the smallest change compared with that of other provinces. The average treatment effect of farmers' adoption intensity of SAPs in Yunnan Province is 0.709, indicating that land tenure stability may increase farmers' adoption intensity of SAPs as high as 54.41%. Figure 4 shows that most of farmers adopt two or three SAPS in Guangdong and Hainan. In Yunnan, farmers who adopt only one SAP account for the largest proportion (45.70%). In particular, 20.97% of the farmers from Yunnan have not adopted any SAPs, while the proportion of non-adopters in Guangdong and Hainan is 5.63% and 0.87%, respectively. The adoption intensity of SAPs is distinct in three provinces, since the degree of the economic development of these provinces is different.

Table 6 Average treatment effect of land tenure stability on farmers' adoption intensity of SAPs

	adoption intensity		ATT	t-value	Change (%)
Farm size	Control group	Treated group			
Larger	1.264	1.843	0.579 (0.069)	8.416***	45.81
Smaller	2.326	2.105	-0.221 (0.063)	-3.530***	9.50

Note: Standard error is in parentheses, and ***, **, * represent significance level at 1%, 5%, 10%, respectively.

Table7 Average treatment effect of land tenure stability on farmers' adoption intensity of SAPs

	adoption intensity		ATT	t-value	Change (%)
Province	Control group	Treated group			
Guangdong	1.405	2.009	0.604 (0.028)	21.739***	42.99
Hainan	1.692	2.012	0.320 (0.032)	9.957***	18.91
Yunnan	1.303	2.012	0.709 (0.034)	21.131***	54.41

Note: Standard errors are in parentheses, and ***, **, * represent significance level at 1%, 5%, 10%, respectively.

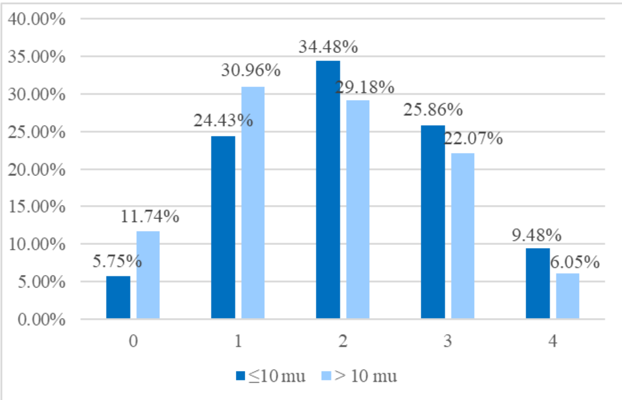


Figure 3 Farmers' adoption intensity of SAPs in different farm sizes

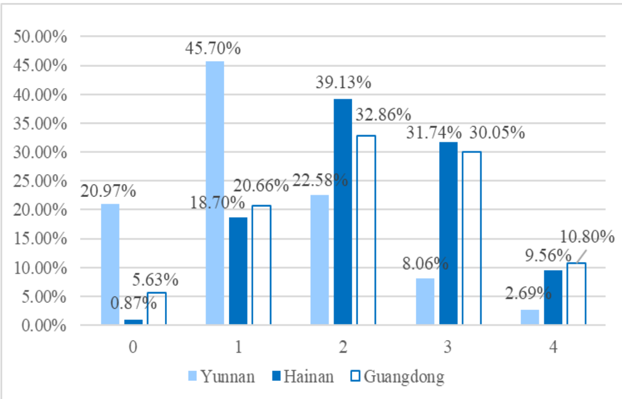


Figure 4 Farmers' adoption intensity of SAPs in different provinces

4.4 Robustness

Two strategies are used to examine the robustness of ESR estimation. One is using an alternative econometric model. The PSM estimation has been commonly used in previous studies to solve the endogenous problem (e.g., Shiferaw et al., 2013; Adane et al., 2019), so it can be used to check the robustness of ESR estimation. The estimated results are presented in Table 8. It shows that the coefficient of ATT is significant with a positive sign, indicating that land tenure stability may increase farmers' adoption intensity of SAPs by 4.95%. Although the value of the average treatment effect is different from that in the results of the ESR model, it confirms that the result of ESR model is robust enough.

The second strategy is changing the outcome variable in the ESR model. We replace *Adoption intensity* with *Adoption ratio*. As illustrated in Table 9, the average treatment effect of *Land tenure stability* on *Adoption ratio* also shows a significant and positive sign. It suggests that land tenure stability increased farmers' adoption ratio of SAPs by 40.62%. It also confirms that the result of ESR model is robust. The estimated results in Table 8 and Table 9 present that both coefficients of the average treatment effect are significant with a positive sign, indicating that the results of ESR model is robust.

Table 8 Robustness check by using PSM method

	Adoption intensity of SAPs		ATT	Std. error	Change (%)
	Control group	Treated group			
	2.000	2.099	0.099***	0.132	4.95
Other controls	Yes				
Observations	629				

Note: Standard deviations are in parentheses, and ***, **, * represent significance level at 1%, 5%, 10%, respectively.

Table 9 Robustness check by substituting outcome variable

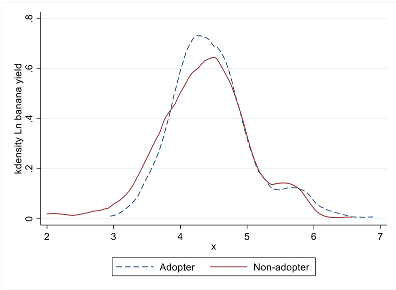
Adoption ratio of SAPs		ATT	t-value	Change (%)
Control group	Treated group			
0.357	0.502	0.145 (0.006)	22.546***	40.62

Note: Standard deviations are in parentheses, and ***, **, * represent significance level at 1%, 5%, 10%, respectively.

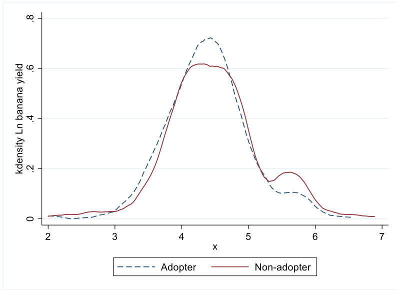
5. Discussion

Existing literature showed that farmers' adoption of SAPs can bring both environmental and economic benefits (Teklewold, 2013; Kassie, 2015a; Manda, 2016). For example, farmers' adoption of new varieties, mini-tiller and sustainable agricultural practices, may help to increase the crop yield and net crop income (Van Vugt et al., 2017; Adane et al., 2019; Gokul et al., 2019; Ma and Wang; 2020). The correlation between farmers' adoption intensity of SAPs and the banana yield is explored in this study. Figure 5 shows the kernel density distribution of banana yield among adopters and non-adopters of SAPs, and the results indicate that adopters had higher banana yield than non-adopters.

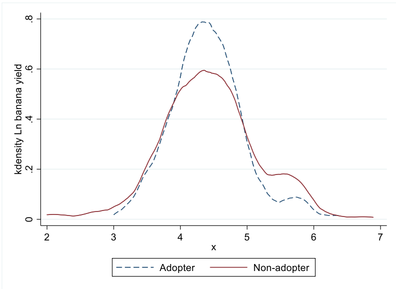
More specifically, the marginal effect of farmers' adoption intensity of SAPs on banana yield is given in Table 10. The coefficient of estimated marginal effect is 0.153 at a significance level of 1%, suggesting that 1% increase in possibility of SAPs adoption intensity could improve banana yield by 15.3%. Farmers' adoption of drip fertigation also has a significant and positive effect on the banana yield. This result is consistent with Abdulai & Huffman (2014) and Wu et al. (2019). The coefficient of farmers' adoption of farmyard manure on the banana yield is not significant in this study, but it still has a positive sign. It implies that application of farmyard manure may promote the yield of banana to some extent. Crop rotation has long been considered to be a sustainable agricultural practice, and its role in maintaining soil fertility and nutrients has been proved by existing literature (e.g. Tilman et al., 2002; Castellazzi et al., 2008; Zhao et al., 2020). Farmers' adoption of crop rotation has a positive impact on banana yield at a significance level of 1%. It is similar to Wang et al. (2018) who had shown that crop rotation is more conducive to the increase of crop yield. The estimated marginal effect of farmers' adoption of fallow on banana yield is 0.015. It shows a positive sign although it is not statistically significant. This finding is consistent with previous study (Oliver et al., 2010). For example, Oliver et al. (2010) found that long fallow yielded more in wheat cultivation. The increase in crop yields can be partly attributed to the soil water and nitrogen (N) accumulated in the fallow period and these soil nutrients are beneficial for future crop growing (Aase and Pikul, 2000; Cann et al., 2020). At the same time, it can control some insect pests and diseases, thus reducing preventive expenditure on agricultural production (Swan et al., 2015).



(a)



(b)



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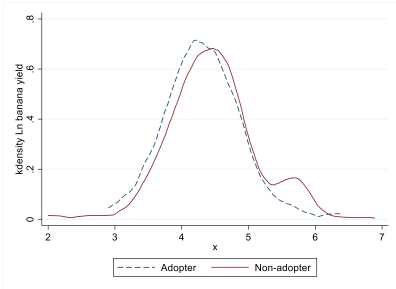

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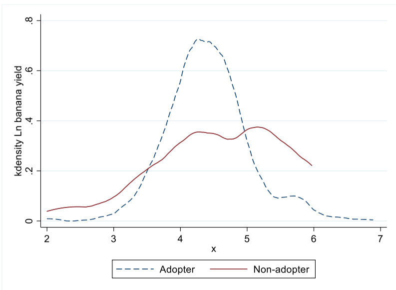

(e)

Figure 5 Kernel density distribution of banana yield between adopters and non-adopters of different technologies.

Table 10 Marginal effect of farmers' adoption of SAPs on banana yield (kg/mu)

	(1) SAPs	(2) Drip fertigation	(3) Farmyard manure	(4) Crop rotation	(5) Fallow
Marginal effect	0.153***	0.104***	0.023	0.134***	0.015
	(0.056)	(0.028)	(0.030)	(0.029)	(0.029)
Other controls	Yes	Yes	Yes	Yes	Yes
Observations	625	625	625	625	625

Notes: Standard deviations are in parentheses, and ***, **, * represent significance level at 1%, 5%, 10%, respectively.

6. Conclusion

The adoption of SAPs may improve the ecological system and bring economic returns of crops (Wossen et al., 2015; Midingoyi et al., 2019; Ma and Wang, 2020). Land tenure stability was deemed as an important incentive for farmers to adopt innovative technologies in agricultural production (Lee and Stewart, 1983; Soule et al., 2000; Ulrich-Schad et al., 2016; Gao et al., 2018; Ranjan et al., 2019). This study employed ESR model to address the self-selection bias between farmers in the treated group and the control group to analyze banana farmers' adoption decisions in China, and explored the impact of land tenure stability on farmers' adoption intensity of SAPs. We also analyzed the heterogeneous effects of land tenure stability on farmers' adoption intensity of SAPs with considering farm sizes and provinces. Furthermore, we discussed the marginal effects of SAPs adoption on banana yield to understand how SAPs influences the performance of banana productivity.

The main findings of this study are as follows. First, land tenure stability produces statistically significant and positive effect on farmers' adoption intensity of SAPs. This finding is confirmed by the estimation of ESR model, and the ATT estimates suggest that farmers' adoption intensity of SAPs can be increased by 40.59% when holding more stable land resource. It is believed that land tenure stability can promote farmers' adoption of SAPs, and this contributes to the sustainable development of the banana industry in China. Second, the smaller a farmer's farm, the higher the adoption intensity of SAPs. This finding underscores the important role of farmers with larger farm sizes in diffusion of SAPs in agricultural production. Besides, the average treatment effect of farmers' adoption intensity of SAPs in Hainan Province has the smallest change (15.90%), followed by Guangdong Province (30.06%) and Yunnan Province (35.24%). In the past two decades, the banana industry in Hainan Province has been expanding fast, and new ideas and technologies have been brought by the skilled investors from other provinces and have been shared among local farmers. While, banana cultivation in Guangdong and Yunnan is mainly dominated by local farmers, and a significant gap with regard to usage of SAPs still exists between the two provinces and Hainan. Third, the simple kernel density curves reveal that adopters of SAPs produced higher banana yield than non-adopters. The estimations of marginal effects on banana yield also prove that adoption of SAPs can help increase banana yield by 15.3%.

The findings emphasize the importance of land tenure stability on farmers' adoption of SAPs in developing regions, and have several implications. First, the policymakers can develop policies to regulate the land transfer market for ensuring farmers to hold stable land-use rights. For example, encouraging farmers to sign formal and legal contracts in the transactions of land rental market and reinforcing the implementation of contract in accordance with the law. Secondly, local government is expected to provide more agricultural trainings for improving farmers' capability of using SAPs in farming practices appropriately, and the training programs can target farmers based on their different resource endowments and regions. Finally, the policymakers can make better use of existing farmers' organizations (e.g. cooperatives or farm field school) as a platform to share the economic advantages of SAPs, such as increasing the yield. The diffusion of the knowledge about the economic benefits associated with SAPs can reduce the cognitive gap among farmers and improve their adoption of SAPs, especially for farmers who mainly cultivate rented farmland.

This study has limitations. First, some factors that may also affect farmers' adoption of SAPs might be neglected in present study. For example, the emerging information and communication technology (ICT) in rural China, such as smartphone, may improve farmers' understanding of sustainable agriculture greatly and further influence their uptake of SAPs in practices. Thus, how ICT influences farmers' adoption intensity of SAPs can be investigated in future studies. Second, the problem of information loss might still exist and distort the estimation results due to the model setting, though the ESR model is used in this study. Other technique can be used in further studies, such as the multinomial endogenous switching regression model. It can take multiple adoption choices into account. Third, the duration of land rental contract may also affect farmers' decision of using SAPs. The future studies shall have a detailed discussion based on different length of land rental contract between farmers if the data can be obtained.

Data availability statement

The data that support the findings of this study are available from the leading author, Qi Yang, upon reasonable request.

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