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The Effects of Agricultural Socialized Services on Sustainable Agricultural Practice Adoption among Smallholder Farmers in China

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Abstract: In recent years, a growing body of literature has explored the determinants and impacts of sustainable agricultural technologies. However, little is known about the relationship between agricultural socialized services that have reshaped the smallholder agricultural system and promoted scale operation in rural China and environmentally friendly agricultural innovation adoption of the farm. Our study examines the effects of agricultural socialized services on the adoption of sustainable agricultural practices (SAPs). In this study, we capture the number of SAPs adopted, unlike most existing studies that analyze the dichotomous decision of agricultural technology adoption. We apply an endogenous-treatment Poisson regression model to analyze using a national representative farm-level survey data set with 1357 farm households from 132 villages in China. The results show that socialized service use has a significantly positive effect on the number of SAPs adopted. Our results suggest that agricultural socialized services can promote the adoption of sustainable agricultural technologies among smallholders, and thus help transform conventional agriculture into sustainable agriculture.

Keywords: agricultural specialization; agricultural socialized services; SAPs; smallholder farmers; sustainable agriculture; technology adoption

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1. Introduction

Currently, the global food system is facing unprecedented shocks because of climate change, rapid urbanization, and land degradation, which results in uncertainty of agricultural production and poses a threat to crop yield and farmer welfare [1,2]. In order to deal with these unprecedented shocks, policymakers have promoted counter measures to prompt the adoption of agricultural practices.

However, previous studies have shown that the adoption of inappropriate practices may result in various environmental problems, such as water and air pollution, increased soil erosion, and reduction of biodiversity, which in turn pose a potential threat to agricultural productivity, food security, and human welfare [3–5]. These detrimental impacts can be mitigated by developing sustainable agriculture since it enables agriculture to move towards a more sustainable system [5,6]. Sustainable agricultural practices (SAPs) are well known for their features of being environmentally non-degrading, resource-conserving, and sustainable [7]. A growing body of literature has focused on SAPs. SAPs are a set of technologies including crop rotation, improved varieties, farmyard manure, organic fertilizer, water conservation irrigation technology, conservation tillage, integrated pest management (IPM) technology, etc. [3,5,6,8,9].

A wave of studies has investigated the impact of SAPs and found that the adoption of SAPs contributes to improving both economic performance and environmental performance [3,10–12]. For instance, the adoption of IPM technology has a positive impact on farms' yield and income and have a negative impact on insecticide use [3]. Although enormous advantages of SAPs adoption have been confirmed, the adoption rate is still quite low, especially in developing countries [2,3,5,6,13,14]. Hence, identifying the constraints of SAP adoption and facilitating SAP adoption is of significance for promoting farm economic performance in these regions.

China's farming system is dominated by smallholder farmers. Over 98% of the total farms are small-scale farms, and the average farm size is only 0.52 hectares [15]. For smallholder farmers, they are unlikely to make investment in sustainable technologies. On one hand, their willingness and ability to invest in SAPs are constrained because of low capital capacity. On the other hand, smallholders only have limited scope to access the benefits from increasing returns to scale. Moreover, adopting SAPs may not necessarily generate economic returns immediately. Consequently, the adoption of sustainable innovation technologies has been hindered.

Instead, agricultural socialized services, as a specific form of scale service, can substitute land transfer to promote operation scale and reduce agricultural production costs [16]. Agricultural socialized services refer to various agricultural production services provided by the business entities directly engaged in agricultural production, such as pre-production services (e.g., agricultural materials supply), mid-production services (e.g., farming technical support), post-production services (e.g., agricultural product sales), etc. Unlike land transfer with high transfer costs and production risks resulting from unstable transfer period, agricultural socialized service can avoid these disadvantages and enable smallholders to access advanced technological progress at a relatively low cost. Under the support from the Chinese government, SAS developed rapidly. There are 950 thousand specialized service providers, the area of agricultural socialized services provided exceeded 1.67 billion mu (111.33 million hectares), and more than 780 million smallholder farmers benefited in 2021 [17].

It is noteworthy that the development of the agricultural service industry in China has followed the path of some agriculturally developed countries, such as the US and Japan, despite a late start. The agricultural production mode from these countries transformed from traditional agriculture to semi-mechanization between 1860s and 1950s. By the early 21st century, with the application of machinery and advanced technologies, agricultural services have comprehensively been adopted and promoted. Similarly, China has experienced structural transformation. Chinese agricultural production was dominated by smallholder farmers and was mainly dependent on manual labor before 1977. From 1978 to 1999, the massive rural to urban labor migration induced the emergence of mechanization and custom services, which greatly improved productivity and efficiency. Since 2000, agricultural socialized services have become market-oriented and have been widely promoted among smallholder farmers.

Different from other agriculturally developed countries, however, Chinese agriculture is featured by small farm size and severe fragmentation. Meanwhile, rural reforms started since 1979 have induced massive rural to urban labor migration. These issues have made it difficult for smallholder farmers to realize a large scale of agricultural mechanization. Agricultural socialized services seem to be an effective way to deal with these problems, so as to ensure food security [18]. Agricultural socialized services have brought two significant changes in land use patterns in rural China. On one hand, it allows farmers to engage agricultural production, by outsourcing the socialized services, instead of trading the land use rights, which ensures the tenure security. On the other hand, SAS can potentially promote economies of scale and farm efficiency by providing services in a larger scale of farmland, which would address the problem of extremely small, scattered, and fragmented farmland plots, for Chinese farm households on average have four to five plots of land.

Although agricultural socialized services become increasingly popular, especially in rural China, we still have little knowledge about whether and how socialized services may affect farmers' decision regarding SAP adoption. Most of the existing studies exploring the drivers of SAP adoption are concentrated on farm-level and plot-level evidence [5,6,8,11], but they rarely focus on the role of agricultural socialized services. There are several studies aiming to examine the association between agricultural services, including extensive services, information services, and advisory services and SAP adoption, which provide insights and references for exploring the relationship between agricultural socialized service and the adoption of SAPs. For example, several recent studies looked into the role of cooperatives, one of the most important socialized service providers, in SAP adoption and found that cooperative members have higher odds of adoption than non-members [19–21]. However, cooperatives can only partially explain the farmers' decision on SAP adoption, considering that those members tend to adopt homogeneous socialized services. The impact of socialized services on SAP adoption has not yet been fully understood.

Moreover, agricultural socialized services are considered an effective way for small farms to access the same advantages of newly developed technologies as their counterparts do, resulting in productivity improvement [22,23]. Specifically, SAPs refer to a set of agricultural innovation technologies that enable farmers move forward to a farming system that is more sustainable. Has socialized service use has promoted the adoption of SAPs? To answer this question, our study provides a robust estimation of the impact of socialized services on SAP adoption in China's maize production.

The objective of this study is to investigate whether and how farm household decisions on production socialized service use affect the adoption intensity of SAPs, utilizing a survey data set collected in 2019 with 1357 farm households in 13 maize-producing provinces in China. We conduct an endogenous-treatment Poisson regression (ETPR) to address the potential endogeneity arising from selection bias associated with socialized services choice, by considering the observed and unobserved heterogeneities. To our best knowledge, this is among the first to explore the impact of socialized services on the adoption intensity of SAPs among smallholder farmers in China.

2. Literature Review

As is well known, sustainable agriculture contributes to economic and environmental performance, as well as human health [6]. The advantages of SAP adoption have been widely recognized in academia. Despite the fact that the existing literature has showed that SAP adoption has significant positive economic and environmental impact [3,10–12,20], the adoption rate of SAPs is relatively low in developing countries [2,3,12]. Similar evidence is also found in China [5,6].

Previous studies have reached conflicting results regarding the determinants of SAP adoption based on the types and location of agricultural innovative practices [24] and confirmed that farmers' adoption behaviors are heterogeneous. Human attributes, including gender and education level, play an important role in SAP adoption [25]. Additionally, household size [26], extension institutions [27], land tenure [6], production shocks [28], and climatic variables [29] affect farm households' decisions regarding SAP adoption.

Specifically, China is facing unfavorable land and labor resource conditions with extremely small and fragmented farmland, as well as a large number of rural to urban labor migration, resulting in labor shortage in agriculture. Several studies suggest that socialized services, namely specialized services, emerged and promoted agricultural production under such conditions [16,18,30]. The role of agricultural socialized services in SAP adoption has been rarely explored and not yet been fully understood.

Interestingly, several recent studies show that cooperative membership (an importance source of socialized services) has a positive impact on SAP adoption [19–21]. For example, it is found that cooperative membership can increase the adoption of water conservation practices, but it cannot significantly promote the adoption of soil and plant health practices, as well as field management practices [20]. It is noteworthy that the cooperative members tend to make identical decisions regarding socialized service use and SAP adoption since they are likely to imitate each other's behaviors. Meanwhile, the specialized service providers include but are not limited to cooperatives, resulting in limited types of socialized services available for farmers.

More importantly, high cost of innovative technologies makes it unprofitable or even unaffordable for smallholder farmers, who dominate in China's farming system, to adopt SAPs. Consequently, they are unlikely to access the same advanced technologies as their larger counterparts do [22]. Socialized services, therefore, can help decrease the cost of sustainable technologies and increase the availability of SAPs, which contribute to promoting the SAP adoption. Hence, we hypothesize that socialized services have a significantly positive effect on the adoption of SAPs.

3. Materials and Methods

3.1. Data

In this study, we utilized a data set collected from a questionnaire survey conducted by the National Agricultural and Rural Development Research Institute (NARI) at China Agricultural University in 2019. The survey implemented multi-stage sampling for data collection. The survey collected information on crop production, farmland characteristics, household income, farm household, and farmer characteristics.

From November to December 2018, the NARI recruited and trained interviewers, mostly graduate students from universities in Beijing, such as Tsinghua University, Beijing Normal University, China Agricultural University, etc. From January to February 2019, interviewers were asked to go to rural villages to conduct surveys. As our aim was to examine the effects of socialized services on SAP adoption in maize production, we only kept those samples engaging in maize production, and 1357 observations remained. The data set covers 132 villages from 13 provinces, including Anhui, Gansu, Hebei, Henan, Heilongjiang, Hubei, Hunan, Inner Mongolia, Jiangsu, Jilin, Liaoning, Shandong, and Sichuan. Of the 1357 households, 712 outsourced socialized services while 645 households did not.

3.2. Estimation Strategy

3.2.1. Selection Bias and Model Selection

The farm household's decision to outsource socialized services is not random but voluntarily selected. Farms that outsource the socialized services might have heterogeneous characteristics from those that do not outsource socialized services. As such, a self-selection issue exists, it would produce biased estimates to estimate the effects of socialized service use on the intensity of SAP adoption, measured as the number of SAPs adopted applying a traditional Poisson model.

The existing studies exploring the impact of policy program intervention have applied propensity score Matching (PSM) and inverse-probability weighted regression adjusted (IPWRA) approaches [5]. There is an assumption underlying the PSM technique that the estimated results of the treatment effects would be unbiased and consistent only when the treatment model, i.e., the socialized service use model, is correctly specified. However, the estimates would be biased when the outcome model is not correctly specified. The IPWAR estimator, however, can provide more reliable estimation results since it has a doubly robust property. The underlying assumption is that the estimation results would be unbiased and consistent as long as the treatment or outcome model is correctly specified. Both PSM and IPWRA methods can address the endogeneity problem arising from selection bias through observed heterogeneities. However, the results using PSM and IPWAR would be biased when there exist unobserved factors that affect the farm household's decisions to outsource socialized services and to adopt SAPs at the same time [5].

In our study, we apply an ETPR model to examine the effects of socialized service use on SAP adoption, which is a Poisson distributed count variable [5,31]. The ETPR model estimates the Poisson regression model where one of the regressors is an endogenous binary variable (i.e., socialized service use). By using ETPR approach, we can estimate the average treatment effect (ATE) and the average treatment effect on the treated (ATT).

3.2.2. Endogenous Treatment Poisson Regression (ETPR) Model

The ETPR model is a two-stage approach to address the endogeneity of binary treatment variable. The first stage models a household's decision to outsource socialized services. Following the existing studies on mechanization services use [32,33], the households' decision to outsource socialized services is modeled in a random utility framework. Let $Service_i{}^*$ denote the utility differences between outsourcing socialized services (U_{iU}) and not outsourcing socialized services (U_{iN}). The household i would choose to outsource socialized services if $Service_i{}^* = U_{iU} - U_{iN} > 0$. The problem is that these utilities are often subjective and unobservable. Instead, we set up a latent variable model as follows:

$$Service_i{}^* = \alpha_i X_i + \varsigma_i$$
$$Service_i = \begin{cases} 1 \ if \ Service_i{}^* > 0 \\ 0 \quad otherwise \end{cases} \tag{1}$$

In this setting, $Service_i$ is a binary variable, denoting whether household i outsources socialized services ($Service_i = 1$) or not ($Service_i = 0$); $Service_i{}^*$ is a latent variable; αi is a vector of parameters to be estimated; X_i is a vector of variables impacting the socialized service use including, for example, farm size, land quality, land fragmentation, labor migration, farmer characteristics, region characteristics; ς_i is a random error term.

In the second stage, we identify the effects of socialized services on SAP adoption. The SAP adoption is modeled as:

$$SAP_i = \beta_i Service_i + \gamma_i Z_i + \xi_i \tag{2}$$

where SAP_i indicates the number of SAPs adopted by household i; $Service_i$ is a dummy variable for socialized service use; Z_i is a vector of control variables; ξ_i is an error term. β_i measures the effects of socialized services on the intensity of SAP adoption. In the ETPR model, at least one IV is required.

In our case, the IVs would be valid if they affect households' socialized service outsourcing decision but do not directly affect households' SAP adoption decision. Hence, labor migration and land fragmentation variables are used as IVs. On one hand, socialized services are counter measures to address the issue of aging and feminizing of the population in rural China resulting from a large scale of rural to urban labor migration. Labor migration is one of the most important drivers of why socialized services emerged in the first place. However, the labor migration may not necessarily affect a farm household's SAP adoption decision. On the other hand, previous studies show that the adoption of socialized services, mechanization service specifically is largely restricted by land fragmentation in China [30], which does not seem to affect the farm's SAP adoption decision. To verify the validity of the IVs, we conduct a validity test, and the results are shown in Table A1 in the Appendix A.

The estimated coefficients in the ETPR model can only provide information about the relationship between socialized services and SAP adoption. Hence, we follow Stata [31] and Ma and Wang [5] and calculate the ATEs and ATTs to better understand the effects of socialized service use on SAP adoption as follows:

$$ATE_i = E(Y_{1i} - Y_{0i}) = [E(Y_{1i} - Y_{0i}|X_i)] \tag{3}$$

$$ATT_i = E(Y_{1i} - Y_{0i}|Service_i) = E[E(Y_{1i} - Y_{0i}|X_i, Service_i = 1)|Service_i = 1] \tag{4}$$

3.2.3. Variables and Descriptive Statistics

Our primary objective is to examine the effects of socialized service use on SAP adoption. In particular, socialized service use is a dummy variable, which equals to "1" if the farm household adopted socialized services, and "0" otherwise. SAP adoption is a count variable. Following the existing studies [5,6,8,11] and considering the characteristics of Chinese agricultural production, we prepared a list of SAPs for farmers to choose from. The list of SAPs in maize production includes (1) improved variety; (2) non-tillage seeding; (3) soil testing; (4) organic fertilizer; (5) green manure; (6) soil conditioner; (7) IPM technology; (8) water-saving irrigation technology; (9) crop residue retention. A value of 1 is given when a practice was adopted and 0 otherwise. The number of SAP adopted, with a value from 0 to 9, was used to measure SAP adoption. A value of 0 means that the farm household did not adopt any SAPs, and a larger value means stronger intensity of SAP adoption.

In the first-stage estimation of the ETPR model of equation (1), we control for farm household and farmer characteristics, including age, gender, education, cooperative membership, technical guidance, agricultural investment, farm size, as well as region characteristics, following previous studies [30,32–35]. Farmland characteristics, such as, terrain and structure of farmland, self-reported quality of farmland are also controlled in the equation since they would affect households' adoption decisions on farming techniques [30,33,36]. Meanwhile, a variable that indicates whether the land use rights of the farm household were certificated or not is also included in the service adoption equation.

In the second-stage estimation of the ETPR model of Equation (2), we control for the factors that affect the farm household's decision regarding SAP adoption. Previous studies have showed that farm households' decisions on SAP adoption are affected by factors such as the farmer's age, gender, education, farm size, extension services, region characteristics, etc. [2,5]. We control for cooperative membership, agricultural investment, land use rights, farmland characteristics, farmer characteristics, and region characteristics.

A description of the general characteristics of the sample is shown in Table 1. The average farm size is only 1.297 hectares, which is extremely small compared with some western countries. According to the classification standard for smallholder farmers by World Bank (2 hectares), Chinese agriculture is basically dominated by smallholder farmers. Of the 1357 survey farms, about 52.5% of them outsourced socialized services, while the rest used traditional farming techniques or purchased agricultural machinery instead. Moreover, of the 9 SAPs, on average each farm adopted 2.202 SAPs, indicating a low adoption rate of SAPs in China's maize production.

Table 2 reports the descriptive statistics of the SAP adoption. It shows that improved variety and crop residue retention are the most frequently adopted SAPs among farmers. Specifically, 61.8 and 58.1% of farms adopted improved variety and crop residue retention practices, respectively. Soil conditioner and IPM technology are the two least adopted SAPs by survey farmers. Particularly, only 9.8% of the households applied soil conditioner, and only 7.7% of farms adopted IPM technology. Moreover, around 12.7% of farmers applied green manure, 12.9% of them adopted green manure, 15.2% of them adopted soil testing fertilization technology, and 16.2% of them adopted organic fertilizer.

Table 1. Variable and definition.

Variable	Definition and Descriptions	Mean	Std. Dev
SAP adoption	Ordered variable, the number of SAPs adopted in 2018 (0–9)	2.202	1.517
Socialized services	Dummy variable, "1" if the household outsourced socialized services, i.e., seeds purchasing, tillage, sowing, pest control, irrigation, harvesting, transportation, or drying services, "0" otherwise	0.525	0.5
Labor migration	Continuous variable, measured as the percentage of household members employed in a non-agricultural sector	0.392	0.399
No. of plot	Continuous variable, the number of plots of operated land	5.296	6.059
Cooperative	Dummy variable, "1" if the farmer once was cooperative member, "0" otherwise	0.141	0.349
Ag. investment	Continuous variable, measured as the depreciation expense of fixed assets (CNY), in natural log	1050.13	7561.671
Farm size	Continuous variable, measured as the operated area of maize cropland (ha), in natural log	1.297	2.611
Land quality	Ordered variable, the self-reported quality of the operated land, "1" if the land is barren, "2" if low quality, "3" if medium, "4" if medium to high, and "5" if extremely fertile	2.982	0.807
Hilly land ratio	Continuous variable, the percentage of hilly land in the total operated land area	0.13	0.302
Paddy land ratio	Continuous variable, the percentage of paddy field in the total operated land area	0.05	0.174
Land use rights [1]	Dummy variable, "1" if the land use rights were registered and certificated, "0" otherwise	0.985	0.121
Social capital	Continuous variable, measured as the number of friends or acquaintances that the farmer reached out to, via WeChat, phone calls, or meetings, during spring festival	29.168	50.534
Technical guidance	Dummy variable, "1" if the household has received technical guidance, "0" otherwise	0.189	0.391
Age	Continuous variable, age of the household head, in natural log	52.661	11.103
Male	Dummy variable, "1" male, "0" female	0.761	0.426
Education	Ordered variable, education level of the household head, "1" illiterate, "2" elementary school, "3" middle school, "4" high school or vocational high school, "5" three-year college, and "6" college or post-graduate	2.745	0.923
East	Dummy variable, "1" if household is located in eastern region [2], "0" otherwise	0.39	0.488
Central	Dummy variable, "1" if household is located in central region, "0" otherwise	0.478	0.5
West	Dummy variable, "1" if household is located in western region, "0" otherwise	0.132	0.339

[1] Land use rights refer to the registration and certification of farmland. Since the No. 1 central document in 2013 was issued, the farmland registration and certification program in rural China started. The farmland ownership, farmland tenure (land use rights), and other rights were confirmed. Each plot must go through farmland registration procedures including farmland registration application, cadastral investigation, affiliation verification, registration, and certification. [2] The provinces were categorized into three regions by the geographic location. Eastern region includes Hebei, Jiangsu, Liaoning, and Shandong. Central region includes Anhui, Henan, Heilongjiang, Hubei, Hunan, Inner, Jilin, and Mongolia. Western region includes Gansu and Sichuan.

Table 2. Definition and descriptive statistics of nine SAPs.

SAPs	Definition and Descriptions	Mean	Std. Dev
Improved variety	"1" if improved variety is adopted, "0" otherwise	0.618	0.486
Non-tillage seeding	"1" if non-tillage seeding technology is adopted, "0" otherwise	0.129	0.335
Soil testing	"1" if soil testing fertilization technology is adopted, "0" otherwise	0.152	0.359
Organic fertilizer	"1" if organic fertilizer is applied, "0" otherwise	0.162	0.369
Green manure	"1" if green manure is applied, "0" otherwise	0.127	0.333
Soil conditioner	"1" if soil conditioner is applied, "0" otherwise	0.098	0.297
IPM technology	"1" if integrated pest management technology is adopted, "0" otherwise	0.077	0.267
Water-saving irrigation	"1" if water-saving irrigation technology is adopted, "0" otherwise	0.258	0.438
Crop residue retention	"1" if straw mulching technology is adopted, "0" otherwise	0.581	0.494

Figure 1 presents the sample distribution of the SAP adoption. It shows that about 9.21% of farms did not adopt any SAPs. Among those that adopted SAPs, 28.74% of them adopted two SAPs, and 27.41% of them adopted one SAP. Only 1.84% of households adopted more than six SAPs, indicating a low rate of SAP adoption in China's maize production.

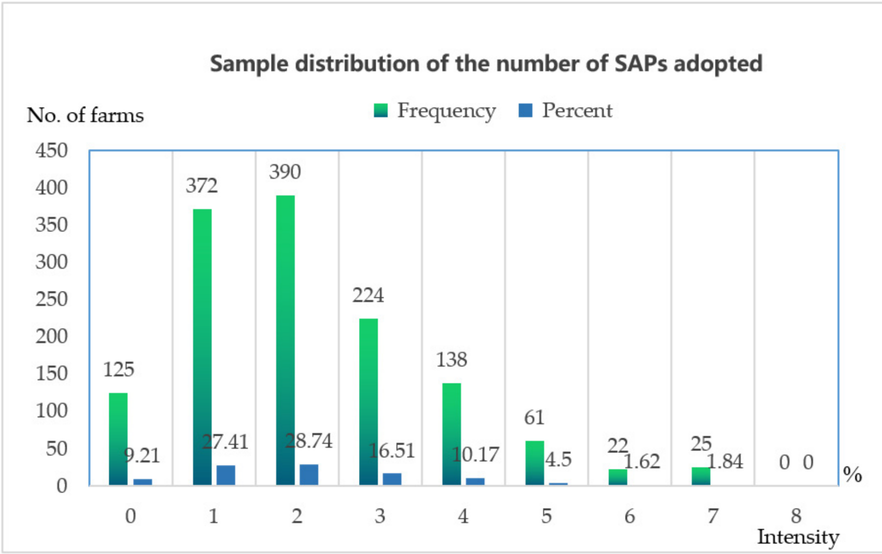

Figure 1. Sample distribution for SAPs adoption.

Table 3 reports a statistical description of variables. There are 712 farms that outsourced socialized services, accounting for 52.47% of the total farms in 2018. The average SAP adoption of farms that outsourced socialized services was significantly higher than that of farms that did not outsource socialized services. In addition, farms outsourcing socialized services operated on smaller farmland than others. Moreover, the labor migration is more serious for farms outsourcing socialized services, implying the labor substitution effects of socialized services.

Table 3. Mean differences of variables between socialized service users and non-users.

Variable	Socialized Service Users		Non-Users		*t* Test Diff.
	Mean	Std. Err.	Mean	Std. Err.	Mean
SAP adoption	2.506	0.059	1.867	0.054	0.639 ***
Farm size (ha)	1.238	0.105	1.361	0.094	−0.123
Labor migration	0.43	0.015	0.35	0.016	0.080 ***
No. of plot	4.154	0.129	6.555	0.308	−2.401 ***
Hilly land ratio	0.061	0.007	0.205	0.015	−0.144 ***
Social capital	32.541	1.633	25.445	2.245	7.096 **
Technical guidance	0.213	0.015	0.161	0.014	0.052 **
Number of farms	712		645		1357

Note: *** $p < 0.01$, ** $p < 0.05$.

4. Results and Discussion

4.1. ETPR Model Results

Table 4 reports the results for the effects of socialized services on SAP adoption. It shows that the correlation between the outcome error and treatment-assignment error is significant and negative, indicating the presence of negative selection bias. It suggests that there are unobservable factors that positively affect the socialized service use and negatively affect SAP adoption. That is to say, the Poisson regression, PSM, and IPWRA technique would underestimate the effects of socialized services on SAP adoption. Instead, the ETPR model can obtain unbiased results.

Table 4. Effects of socialized service use on SAP adoption.

Variable	(1)	(2)	(3)	(4)	(5)
	ETPR			Poisson Regression	
	Socialized Service (Coefficients)	SAP Adoption (Coefficients)	(IRRs)	SAP Adoption (Coefficients)	(IRRs)
Socialized services		0.335 ***	1.398 ***	0.262 ***	1.300 ***
		(0.116)	(0.162)	(0.041)	(0.054)
Cooperative	0.066	0.192 ***	1.212 ***	0.194 ***	1.214 ***
	(0.109)	(0.050)	(0.061)	(0.050)	(0.061)
Farm size	0.109 **	0.037 *	1.038 *	0.037 *	1.038 *
	(0.045)	(0.019)	(0.020)	(0.019)	(0.020)
Ag. investment	−0.041 ***	−0.014 **	0.986 **	−0.015 **	0.985 **
	(0.013)	(0.007)	(0.007)	(0.006)	(0.006)
Hilly land ratio	−0.595 ***	−0.276 ***	0.759 ***	−0.293 ***	0.746 ***
	(0.146)	(0.078)	(0.060)	(0.074)	(0.055)
Paddy land ratio	−0.490 *	0.254 **	1.289 **	0.238 **	1.269 **
	(0.263)	(0.109)	(0.140)	(0.106)	(0.134)
Land quality	0.063	−0.034	0.966	−0.033	0.968
	(0.047)	(0.024)	(0.023)	(0.023)	(0.023)
Land use rights	0.327	0.302 *	1.352 *	0.312 *	1.367 *
	(0.297)	(0.174)	(0.235)	(0.173)	(0.236)
Technical guidance	0.226 **	0.251 ***	1.285 ***	0.256 ***	1.292 ***
	(0.100)	(0.046)	(0.059)	(0.045)	(0.058)
Social capital	0.001	0.001 **	1.001 **	0.001 ***	1.001 ***
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Age	0.004	0.001	1.001	0.001	1.001
	(0.004)	(0.002)	(0.002)	(0.002)	(0.002)
Male	0.174 **	0.012	1.012	0.017	1.017
	(0.089)	(0.045)	(0.046)	(0.045)	(0.046)
Education	0.070	0.036	1.037	0.038 *	1.039 *
	(0.045)	(0.022)	(0.023)	(0.022)	(0.023)
East	1.515 ***	−0.130	0.878	−0.092	0.912
	(0.150)	(0.091)	(0.079)	(0.071)	(0.065)
Central	1.025 ***	−0.012	0.987	0.013	1.013
	(0.150)	(0.078)	(0.077)	(0.068)	(0.069)
Labor migration	0.370 ***				
	(0.097)				
No. of plot	−0.038 ***				
	(0.011)				
_cons	−2.137 ***	0.142	1.153	0.133	1.143
	(0.451)	(0.236)	(0.272)	(0.235)	(0.268)
rho		−0.927 **			
		(0.116)			
Obs.	1357	1357	1357	1357	1357

Note: Standard errors are in parenthesis, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

In this section, we first analyze the drivers of socialized service use and then discuss the determinants of SAP adoption. Next, we present and discuss the treatment effects of socialized services on SAP adoption.

4.1.1. Determinants of Socialized Service Use

The results show that the farm households' decision regarding socialized service adoption is correlated with farmland characteristics. In particular, farm size has a positive effect on socialized service use and land fragmentation exerts a negative effect. The coefficient of hilly land ratio is significant and negative, suggesting that unfavorable terrain of cropland has restricted the socialized service use. It is probably because a large scale of specialized services could not be realized easily on farmland with unfavorable terrain and charges may be higher. Additionally, the socialized service adoption decision is correlated with household characteristics. The coefficient of male is positive at the 5% level, which suggests that male household heads are more likely to use socialized services. Our findings are consistent with the existing studies [33]. Farms in eastern and central regions have higher probability for socialized service use. Technical guidance increases the probability of socialized service use. This finding implies that technical guidance enables farmers to have more information about socialized services and thus prompt socialized service use. More importantly, labor migration has a significantly positive effect on socialized service use, which is consistent with the existing findings [33,34]. It denotes that the large scale of rural to urban migration may have induced emergence of specialized services in China [18,37]. Agricultural investment has a significantly negative effect on socialized service use, implying that outsourcing socialized services can replace self-owned agricultural machinery and thus enable smallholder farmers to access the benefits of technological progress [22].

4.1.2. Determinants of SAP Adoption

The determinants of SAP adoption are shown in the column (2) of Table 4. Following Ma and Wang [5], we report the incidence rate ratios (IRRs) in column (3) to interpret the results, considering that the coefficients from a count model are not straight forward. Specifically, we can obtain IRRs by exponentiating the estimated coefficients from the count model, i.e., IRR = exp (coefficient). Additionally, we examined the effects of socialized service use on SAP adoption applying a Poisson model. The coefficients and IRRs are shown in column (4) and (5) of Table 4.

The IRR of socialized service variable in the ETPR model is significantly positive, which means that farms outsourcing socialized services adopted 1.398 times more SAPs than those that did not outsource services. In our sample, over half of the farms (65.48%) adopted less than three SAP(s) (shown in Figure 1), which here shows the important role of socialized services in promoting environmental and friendly innovation adoption. The possible mechanism is that socialized services help increase the availability of newly developed sustainable technologies and prompt farmers' knowledge and recognition about the advantages associated with these technologies, which eventually promotes SAP adoption. Meanwhile, the IRR results from traditional Poisson model show that farms outsourcing socialized services adopted 1.300 times more SAPs than those that did not outsource services. The IRR estimates using the Poisson model are smaller than using the ETPR model, indicating that the traditional Poisson model underestimated the effects of socialized service on SAP adoption. It seems to be plausible since the Poisson model does not consider selection bias issue relevant to socialized service use. As stated above, there exists a negative selection bias ($\rho = -0.927$).

In terms of other factors affecting the SAP adoption, the cooperative variable has a significant and positive coefficient, suggesting that cooperative members tend to adopt more SAPs. It is consistent with previous studies [19,20]. Farm size has a positive effect on SAP adoption, which means that large farms tend to adopt more SAPs than their small counterparts. Agricultural investment has a significantly negative coefficient, which suggests that farms that own more machinery are less likely to adopt SAPs. Hilly land ratio has a significantly negative effect on SAP adoption, meaning that farms with hilly land tend to adopt fewer SAPs. A possible explanation is that sustainable technologies are not easily applied, resulting in higher charges. The IRR estimate shows that farms that registered land use rights adopted 1.352 times more SAPs than those who did not register land use rights. It means that land tenure stability has a significantly positive effect on the number of SAPs adopted, which is consistent with the existing findings [6]. The coefficient of social capital is positive and significant, which means that households with higher social capital tend to adopt more SAPs. The IRR estimate shows that farms that received technical guidance adopted 1.285 times more SAPs on average than those that did not receive any technical guidance. Consistent with the existing findings, extension services can promote the adoption of sustainable technologies in agriculture [27].

4.1.3. Treatment Effects of Socialized Services Use on SAP Adoption

The results of IRRs reported in Table 4 show the effects of socialized services on SAP adoption from a marginal perspective. To better understand the issue, we estimate the treatment effects of socialized service use on the number of SAPs adopted, following Ma and Wang [5] and Stata [31]. The results are presented in Table 5.

Table 5. Treatment effects of socialized service use on SAP adoption.

Model	ATE		ATT	
	Coef.	Std. Err.	Coef.	Std. Err.
ETPR model	0.727 ***	0.252	0.713 ***	0.211
PSM technique [1]	0.616	-	0.492 ***	0.117
IPWRA	0.569 ***	0.087	0.451 ***	0.089

[1] Nearest neighbor matching is employed. Standard errors are presented in parenthesis, *** $p < 0.01$.

The ATE of socialized service use on SAP adoption is 0.727, which suggests that on average the farm households would adopt 0.727 more SAPs when they outsourced socialized services. The ATT of socialized service use on SAP adoption is 0.713, indicating that on average the farm households that outsourced socialized services would adopt 0.713 more SAPs than they would if they did not outsource socialized services. Overall, the results verified our hypothesis that socialized service use can promote SAP adoption in China's maize production.

For comparison, we also reported the ATEs and ATTs of socialized service use on SAP adoption applying the PSM approach and IPWRA. We can see that the ATEs of socialized service use on SAP adoption using PSM and IPWRA approaches are 0.616 and 0.569, while the ATTs are 0.492 and 0.451, respectively. Our results suggest that socialized services can promote SAP adoption in China's maize production, which once again verified our hypothesis. It is noteworthy that the estimated ATEs and ATTs using both PSM and IPWRA are smaller than that using ETPR. It is quite plausible, as both approaches did not consider the unobserved selection bias and thus underestimated the effects of socialized services on SAP adoption.

4.2. Robustness Check

To check the robustness of the empirical results, we applied a two-stage probit-IV approach and copula correction method. The results are shown in Table 6. These two methods were chosen to conduct a robustness check to address the potential problem of weak instrumental variables for socialized service use in the ETPR, although we have conducted a validity test.

In the probit-IV approach, we first run a probit regression on farmer's decision regarding socialized service use and then apply the fitted values as the IV for socialized services in the second stage IV estimation. The results are shown in column (1) and column (2). We can see that our results are quite consistent with our baseline results; that is, the socialized service use has a significantly positive effect on SAP adoption.

More importantly, we apply the copula correction method, proposed by Park and Gupta [38], to further examine the impacts of socialized services on SAP adoption. Copula correction is a statistical approach to address the endogeneity issue without requiring external instrumental variables. The copula correction utilizes information from the observed data and selects marginal distributions for the structural error term and the endogenous regressor, respectively. It helps construct a flexible multivariate joint distribution that allows various correlations between these two marginal distributions. The estimation can be done using the copulaCorrection command from the REndo package in RStudio. For discrete endogenous regressors, we have to assign a random seed since the marginal distribution function of the endogenous regressor is a step function. In our study, we assigned the seed to 20 and 30, to test the robustness, and the results are shown in column 3 and column 4, respectively. We can see that socialized services have significant and positive coefficient in both cases, suggesting that socialized services have promoted the number of SAPs adopted by farm households.

Table 6. Results of robustness check.

Variable	(1)	(2)	(3)	(4)
	Probit-IV		Copula Correction	
	Socialized Services	SAP Adoption	SAP Adoption Seed (20)	SAP Adoption Seed (3)
Socialized services		1.617 ***	0.436 **	0.602 **
		(0.557)	(0.129)	(0.130)
Cooperative	0.067	0.459 ***	0.482 **	0.480 **
	(0.109)	(0.119)	(0.105)	(0.104)
Farm size	0.109 **	0.093 **	0.105 **	0.104 **
	(0.045)	(0.043)	(0.042)	(0.042)
Ag. investment	−0.041 ***	−0.021	−0.035 **	−0.035 **
	(0.013)	(0.016)	(0.013)	(0.013)
Hilly land ratio	−0.585 ***	−0.277	−0.511 **	−0.508 **
	(0.145)	(0.193)	(0.128)	(0.129)
Paddy land ratio	−0.489 *	0.804 ***	0.602 **	0.605 **
	(0.265)	(0.280)	(0.253)	(0.257)
Land quality	0.062	−0.094 *	−0.071	−0.068
	(0.047)	(0.053)	(0.047)	(0.047)
Land use rights	0.331	0.519	0.645	0.659
	(0.297)	(0.345)	(0.371)	(0.379)
Technical guidance	0.223 **	0.566 ***	0.650 **	0.645 **
	(0.100)	(0.115)	(0.114)	(0.113)
Social capital	0.001	0.002 **	0.003 **	0.003 **
	(0.001)	(0.001)	(0.001)	(0.001)
Age	0.004	0.003	0.003	0.003
	(0.004)	(0.004)	(0.004)	(0.004)
Male	0.176 **	−0.028	0.030	0.032
	(0.089)	(0.102)	(0.090)	(0.088)
Education	0.069	0.051	0.075	0.076
	(0.045)	(0.051)	(0.052)	(0.051)
East	1.513 ***	−0.702 **	−0.176	−0.172
	(0.151)	(0.318)	(0.136)	(0.136)
Central	1.026 ***	−0.293	0.054	0.058
	(0.150)	(0.237)	(0.136)	(0.134)
Labor migration	0.369 ***		0.063	0.055
	(0.097)		(0.099)	(0.099)
No. of plot	−0.038 ***		−0.004	−0.004
	(0.011)		(0.007)	(0.008)
_cons	−2.128 ***	0.887 *	0.819	0.709
	(0.451)	(0.488)	(0.494)	(0.488)
P*_Socialized services			0.073	−0.028
			(0.062)	(0.062)
Obs.	1357	1357	1357	1357

Note: Standard errors are in parenthesis, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Models (3) and (4) employ copula correction analysis. Bootstrapping standard errors are in parenthesis, 1000 bootstraps.

5. Conclusions

Although numerous previous studies have shown socialized services can improve the economic and environmental performance of the farms, we still have little knowledge about whether socialized services can prompt SAP adoption. Our study analyzed the effects of socialized service use on SAP adoption applying an ETPR model that explicitly considers the potential selection bias related to socialized service use.

We show that socialized service use has a significantly positive effect on SAP adoption. Specifically, farms that outsourced socialized services adopted 1.398 times more SAPs than those that did not outsource socialized services. The results of estimated ATEs and ATTs applying PSM and IPWAR approaches further provide evidence for the positive effects of socialized service use on SAP adoption. In addition to socialized services, we show that SAP adoption is also significantly and positively affected by farm size, social capital, cooperative membership, technical guidance, land use rights, and farmland characteristics. Moreover, we show that farm households' decisions to outsource socialized services are mainly driven by labor migration, farm size, land fragmentation, agricultural investment, technical guidance, gender of household heads, farmland characteristics, and region characteristics.

The findings that socialized service use can facilitate SAP adoption highlight the significance of agricultural production services in China's farming system. It implies that to promote SAP adoption, the policy makers should encourage the socialized services use through subsidy, as well as the investment on the availability of socialized services. Meanwhile, policies should be focused on providing agricultural extension service programs to help farm households to better understand the benefits associated with SAPs in practice. Prompting the accessibility of agricultural socialized services can be an effective strategy.

This study has certain limitations. It might experience omitted variable problems since we concentrated on SAP adoption in maize production and did not take into account the heterogeneities among different farming systems. So, future work would explore the differences in socialized service use affecting SAP adoption among different crops or livestock production. Furthermore, as different types of socialized services may produce different impacts on SAP adoption, the estimations relying on a dummy variable might encounter problems of information loss. Hence, future work would apply more valid and robust estimation techniques that can help account for multiple socialized service adoption decisions and analyze how farm households' decisions on the individual and combined SAP(s) affect outputs.

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Appendix A

Table A1. Results of validity test of the IVs.

Variable	OLS			IV
	SAPs	Socialized Services	SAPs	SAPs
Socialized services	0.616 ***		0.601 ***	1.614 **
	(0.084)		(0.084)	(0.724)
Labor migration		0.118 ***	0.144	
		(0.032)	(0.099)	
Land fragmentation		−0.006 **	−0.004	
		(0.002)	(0.008)	
Cooperative	0.372 ***	0.029	0.367 ***	0.335 ***
	(0.111)	(0.036)	(0.112)	(0.119)
Farm size	−0.038	0.037 **	−0.020	−0.052
	(0.044)	(0.016)	(0.048)	(0.047)
Ag. investment	−0.026 **	−0.015 ***	−0.028 **	−0.013
	(0.013)	(0.004)	(0.013)	(0.017)
Hilly land ratio	−0.549 ***	−0.205 ***	−0.535 ***	−0.318
	(0.133)	(0.044)	(0.136)	(0.217)
Paddy land ratio	0.797 ***	−0.194 **	0.820 ***	1.046 ***
	(0.237)	(0.080)	(0.249)	(0.306)
Land quality	−0.072	0.024	−0.071	−0.097 *
	(0.048)	(0.015)	(0.048)	(0.053)

Table A1. *Cont.*

Variable	OLS			IV
	SAPs	Socialized Services	SAPs	SAPs
Land use rights	0.666 **	0.122	0.644 **	0.525
	(0.313)	(0.102)	(0.314)	(0.343)
Technical guidance	0.551 ***	0.084 **	0.554 ***	0.467 ***
	(0.102)	(0.033)	(0.102)	(0.122)
Social capital	0.003 ***	0.000	0.002 ***	0.002 **
	(0.001)	(0.000)	(0.001)	(0.001)
Age	0.005	0.001	0.006	0.005
	(0.004)	(0.001)	(0.004)	(0.004)
Male	−0.007	0.061 **	−0.006	−0.070
	(0.090)	(0.029)	(0.091)	(0.105)
Education	0.118 **	0.019	0.118 **	0.099 *
	(0.047)	(0.015)	(0.047)	(0.051)
East	−0.133	0.485 ***	−0.135	−0.633
	(0.141)	(0.044)	(0.142)	(0.388)
Central	−0.083	0.336 ***	−0.089	−0.441
	(0.137)	(0.044)	(0.140)	(0.295)
Subsidy	0.823 ***	−0.093 ***	0.841 ***	0.932 ***
	(0.109)	(0.035)	(0.110)	(0.138)
_cons	0.720	−0.184	0.634	0.840 *
	(0.451)	(0.147)	(0.455)	(0.479)
Obs.	1357	1357	1357	1357

Note: Standard errors are in parenthesis, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

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