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Influence of a new agricultural technology extension mode on farmers' technology adoption behavior in China

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ABSTRACT

With the development of Internet information technology and portable mobile terminals, a new agricultural technology extension mode has emerged that uses new media such as WeChat public accounts and apps. However, empirical studies on the effectiveness of the new agricultural technology extension mode have not been reported. To compensate for the shortage of existing research, this article uses survey data from 759 peasant households in Shandong Province and Henan Province to measure soil fertilizer technology, water-saving irrigation techniques and the prevention and control of plant diseases and insect pests through green technology. A score matching method is used to explore new agricultural technology extension modes for farmers' direct effects and spillover effects from technology adoption behavior as well as distribution effects. A robustness inspection instrumental variable method is used to identify the effectiveness of the new agricultural technology extension mode and provide extensive information to evaluate the effectiveness of the analytical framework. The study finds that the new agricultural technology extension mode improves the technology adoption level of farmers to a certain extent with a partial spillover effect, and farmers of different ages and with different sizes of farmland benefit differently. When guiding farmers to use the new agricultural technology extension mode, it is important to consider the information diffusion among farmers who have already adopted this mode and to disseminate this information to elderly and small-scale farmers.

1. Introduction

The extension of agricultural technology is an important means of accelerating the transformation of agricultural scientific and technological achievements and promoting the development of agricultural modernization. With the development of Internet information technology and portable mobile terminals, agricultural technology extension in China can be divided into a traditional mode and a new mode (Yin et al., 2018). Traditional agricultural technology extension methods primarily include on-site guidance, technical training, scientific and technological demonstration and mass media (newspapers, radio and television) publicity (Liu and Peng, 2017). A new agricultural technology extension mode involves releasing technical information, solving farmers' technical problems online, and providing farmers with agricultural technology support through new media, such as agricultural technology WeChat public accounts and agricultural technology extension mobile phone applications (apps) (Li et al., 2018). Limited by the insufficient number and low quality of agricultural technology promoters, traditional agricultural technology extension methods are not only unable to directly provide services to all farmers (Tong et al., 2018) but are also increasingly unable to meet the information needs of farmers for efficient, accurate, real-time, convenient and personalized interaction (Nakano et al., 2018). In theory, a new agricultural technology extension mode that can overcome the limitations of the traditional mode of agricultural technology can satisfy not only farmers' "number" of agricultural technology information requirements but also farmers' "quality" of agricultural technology information requirements. Traditional agro-technique extensions can provide complementary advantages to effectively solve the agricultural technology "last kilometer" problem in China (Gu, 2013). However, relevant empirical studies have not been reported. Based on survey data of 759 households in Shandong and Henan provinces, this paper conducts an empirical study of the impact of the new agricultural technology extension mode on farmers' technology adoption behaviors to

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compensate for the shortcomings of existing studies. Given the wide range of agricultural technologies, this paper takes soil testing and fertilization technologies, water-saving irrigation technologies, and pest control technologies as examples for empirical analysis (Yin et al., 2017).

To comprehensively evaluate the effectiveness of the new agricultural technology extension mode, this paper discusses the direct effect of the new agricultural technology extension mode and further analyzes the spillover effect and distribution effect of this new mode. This is because communication between neighbors is an important channel for farmers to obtain agricultural technology information (Taylor and Bhasme, 2018). This means that although some farmers do not directly use the new agricultural technology, because other farmers in the same village use the new mode, through extensive communication and contact, farmers who do not use the new agricultural technology extension mode may benefit from it; that is, a spillover effect exists. The spillover effect is discussed by taking the technical training and technology demonstration in traditional agricultural technology extension as examples. According to Altalb (2017), technical training has enhanced the exchange of information between farmers in the same village in Poland and promoted the adoption of technology by farmers who have not received training. Tong et al. (2018) found that technology demonstration significantly improved the technology adoption level of non-demonstration households in demonstration villages. Therefore, it is necessary to pay attention to spillover effects to avoid underestimating the impact of the new agricultural technology extension mode on farmers' technology adoption behavior. At the same time, due to the difference in farmers' factor endowments, farmers have different likelihoods of benefiting from the new agricultural technology extension mode; that is, a distribution effect exists. By analyzing the distribution effect, we can more comprehensively evaluate the influence of the new agricultural technology extension mode on farmers' technology adoption behavior.

To deal effectively with the endogeneity problem, this paper uses the propensity score matching (PSM) method for estimation and the instrumental variable method to test robustness. This is because the unobservable factors that affect farmers' technology adoption behavior may also affect whether they use the new agricultural technology extension mode, which leads to the possibility of an endogeneity problem in research on the influence of the new agricultural technology extension mode on farmers' technology adoption behavior. If the endogeneity problem is not addressed effectively, the influence of the new mode on farmers' technology adoption behavior may be overestimated.

The main contribution of this paper is the development of an extension of the direct effect, spillover effect, and distribution effect assessment framework while effectively managing the endogeneity problem. This paper provides better understanding of the effectiveness of the new agricultural technology extension mode and proposes an extension that can be used to evaluate the effectiveness of the analytical framework. The research conclusions of this paper will provide objective and detailed empirical evidence for the popularization of new agricultural technology extension modes and a reference for the construction of a complementary, collaborative and efficient socialized service system for agricultural technology.

2. Research hypotheses

2.1. Direct effects of the new agricultural technology extension mode

The working mechanisms of the new agricultural technology extension mode are as follows. The agro-technique extension department releases relevant technical information in the form of articles or videos on agricultural technology WeChat public accounts, agricultural technology extension apps and other platforms. Farmers browse the articles or videos or use the platforms to obtain relevant technical information. Then, through sharing and communication, the information is passed to other farmers. The new agricultural technology extension mode has the following characteristics. First, it is flexible. Given the popularity of mobile phones and mobile networks, the articles and videos provided by the agricultural technology WeChat public accounts, agricultural technology extension apps and other platforms can overcome the limitations of space and professional equipment and extend service distribution to grassroots scientific and technological personnel (Gu, 2013). Furthermore, the approach meets the demands of farmers' households for information. Farmers can follow different public accounts or download different mobile apps to customize the relevant technical information according to their needs (Li et al., 2018). Finally, the two-way interaction between extension personnel and farmers should be strengthened. Through the service system of each platform, agricultural technology extension personnel can convey technical information to farmers and receive timely feedback from farmers (Yao and Ding, 2018). Farmers who use the new agricultural technology extension mode to obtain technical information (hereinafter referred to as UF) can not only browse personalized customized information anytime and anywhere but can also interact with online experts in real time to solve the problems in the process of technology use. Therefore, this paper proposes hypothesis 1:

H1. The new agricultural technology extension mode helps to improve farmers' technology adoption rates.

2.2. Spillover effects of the new agricultural technology extension mode

The spillover effect of the new agricultural technology extension mode applies to those farmers who do not use the new agricultural technology extension mode to obtain technical information (hereinafter referred to as NUF). Generally, farmers in the same village have relatively close social connections with a high frequency of online and offline communication (Gao et al., 2017a). NUF may also benefit from the new agricultural technology extension mode by communicating with UF offline or by receiving information about agricultural technology shared and forwarded by UF online. Therefore, this study proposes hypothesis 2:

H2. The new agricultural technology extension mode will also improve the technology of NUF (when UFs exist in the same village).

2.3. Distributional effect of the new agricultural technology extension mode

The distributional effect of the new agricultural technology extension mode refers to the distribution of the benefits of agricultural technology extension among different farmers. Some farmers benefit more, some benefit less, and some do not benefit at all. On the one hand, due to the differences in farmers' technical demands as well as the breadth (online time per week) and depth (number of agricultural technology WeChat public accounts and agricultural technology extension apps) of their use of new media, the direct and indirect benefits to different farmers are different after the release of agricultural technology information on the new media platform. On the other hand, due to differences in farmers' technical characteristics and resource endowments, even if two farmers adopt the same new agro-technical extension service, their actual benefits may vary (Wossen et al., 2017). In view of this, this paper proposes hypothesis 3:

H3. Differences exist in the influence of the new agricultural technology extenfsion mode on adoption rates of the technology by different types of farmers.

3. Research design

3.1. Econometric model

Estimating the impact of the new agricultural technology extension mode on farmers' technical adoption is often affected by endogeneity problems, which leads to overestimation of effectiveness. Therefore, PSM is used in this paper. Adopting this method requires identifying NUF (control group) who have similar characteristics to UF (treatment group) according to observable variables. Therefore, a decision processing group model needs to be constructed first to estimate the probability, that is, a propensity score, of farmers adopting a new agricultural technology extension mode. According to random utility theory, the model to determine the treatment group can be expressed as the latent variable:

$$D_n' = \beta X_n + \mu_n \tag{1}$$

$$D_n \begin{cases} 1, & D_n' > 0 \\ 0, & D_n' \le 0 \end{cases}, \tag{2}$$

where $D_n'$is the potential indicator variable of whether farmers will adopt the new agricultural technology extension mode; $D_n$is the observable explained variable, representing whether farmers truly adopt the new agricultural technology extension mode; $D_n = 1$represents the new agricultural technology extension mode; and $D_n = 0$represents the failure to adopt it. X_n is the control variable that affects farmers' adoption of the new agricultural technology extension mode, β is the vector of coefficients to be estimated, and μ_n is the random disturbance term.

The propensity score can be estimated by the probit model

$$P(X_n) = \mathrm{Prob}(D_n = 1|X_n). \tag{3}$$

After the estimated propensity score, UF and NUF need to be matched according to the matching estimator. A good matching estimator requires a large common support area for the propensity score of UF and NUF after matching. In this study, core matching is used to evaluate the impact of the new agricultural technology extension mode on farmers' technical adoption, and the nearest neighbor matching method is used to test the robustness of the estimation results of the core matching. In addition, the key assumption of PSM is the conditional mean independence assumption (Rosenbaum and Rubin, 1983). However, the conditional mean independence hypothesis cannot be directly tested with nonexperimental data. To ensure that the hypothesis can be established as much as possible, several methods are adopted in this paper. First, observable variables affect farmers' adoption of the new agricultural technology extension mode, and the adoption of technologies is considered to reduce hidden deviations. Second, matching is conducted according to the common value range of the propensity score, and unmatched samples are removed (Heckman et al., 1997). Third, the sensitivity of the results to potential implicit biases is analyzed using the Rosenbaum bounds (Rosenbaum, 2002).

The average treatment effect on the technical treatment (ATT) adopted by the treatment group is used to estimate the impact of the new agricultural technology extension mode on the technical adoption of farmers. The direct effect, spillover effect and distributional effect can be identified by selecting the proper treatment group and control group (Fig. 1).

3.1.1. Direct effects of the new agricultural technology extension mode

Due to the possible technology spillover, interference should be excluded when estimating the direct effect of the new agricultural technology extension mode. To this end, the matching analysis was conducted with UF serving as the treatment group and NUF (with farmers who do not use the new mode present in the same village) as the control group, and the average treatment effect was estimated:

$$ATT' = E(Y_{1n} - Y_{0n}|D_n = 1), \tag{4}$$

where $Y_{1n}$is the observable probability of technology adoption of the treatment group andY_{0n} is the matching probability of technology adoption if the treatment group does not adopt the new agricultural technology extension mode. ATT' represents the average treatment effect of the new agricultural technology extension mode on the technical adoption of UF compared with NUF (with farmers who do not use the new mode present in the same village).[1]

3.1.2. Spillover effects of the new agricultural technology extension mode

To estimate the spillover effect of the new agricultural technology extension mode, the average treatment effect was estimated by taking NUF (with farmers who use the new mode present in the same village) as the treatment group and NUF (with farmers who do not use the new mode present in the same village) as the control group through matching analysis:

$$ATT'' = E(Y_{1n} - Y_{0n}|M_n = 1). \tag{5}$$

In the formula, $M_n = 1$represents NUF (with new mode farmers present in the same village), $M_n = 0$represents NUF (with farmers who do not use the new mode present in the same village), and ATT''represents the average treatment effect of the new agricultural technology extension mode on NUF (new mode farmers present in the same village) compared to NUF (farmers who do not use the new mode present in the same village).

By comparing $ATT'$and ATT'', we can judge whether a spillover effect exists for the new agricultural technology extension mode. (1) Both ATT' and$ATT''$are significant, indicating that the new agricultural technology extension mode has a spillover effect on the technology adoption of NUF (with new mode farmers present in the same village) compared with NUF (with farmers who do not use the new mode present in the same village). (2) $ATT'$is significant but $ATT''$is not significant, indicating that the new agricultural technology extension mode has no spillover effect on the technology adoption of NUF (with new mode farmers present in the same village) compared with NUF (with farmers who do not use the new mode present in the same village).

3.1.3. Distributional effect of the new agricultural technology extension mode

Based on the above analysis, the sample farmers according to the householder age and size of farmland were divided into older farmers (aged 60 and above) and young and middle-aged farmers (under the age of 60), small-scale farmers (below 10 acres) and middle-sized and above farmers (10 acres and above). The effects of the new agricultural technology extension mode on the technical adoption of farmers of different ages and different business scales were investigated.[2]

3.2. Variables and assignments

3.2.1. Explained variables

The explained variables in this paper are adopted behaviors of farmers with regard to soil testing and formulated fertilization technology, water-saving irrigation technology and green control techniques in the formal investigation, all of which are evaluated by 'adopt = 1, not adopt = 0'.

[1] Since the probability of technology spillover is very low for NUF (farmers in the same village who do not use the new technology extension mode), the interference of technology spillover can be eliminated by taking them as the control group.

[2] According to the median of cultivated land scale in the sample data (10 mu), the subsample sizes of the treatment group and the non-treatment group were grouped to better balance the respective subsample sizes.

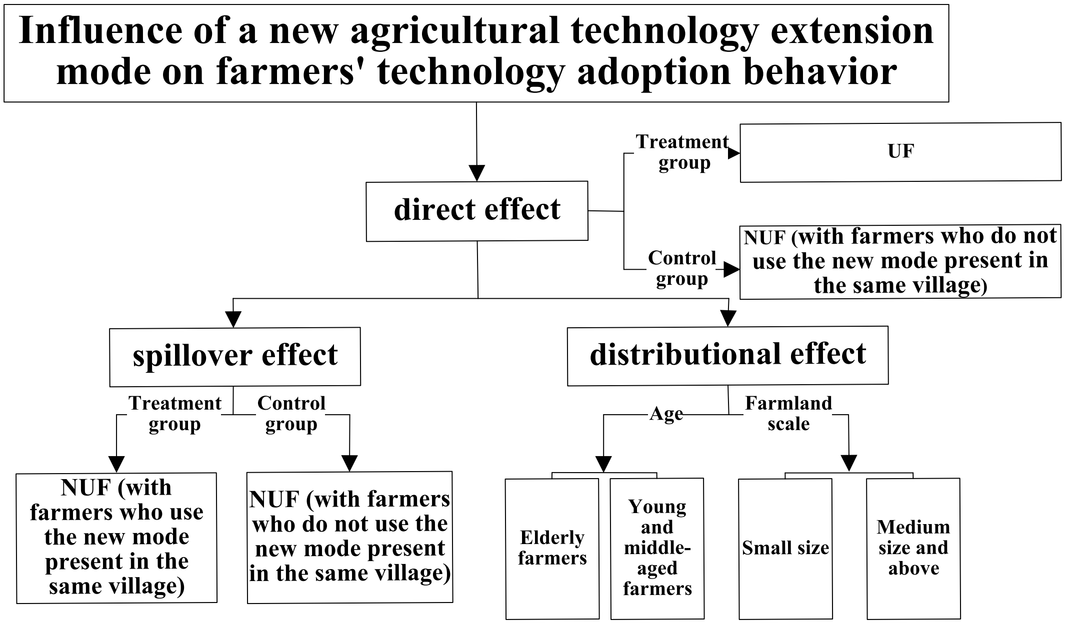

Fig. 1. Overall analytical framework.

3.2.2. Core explanatory variables

The core explanatory variable of this paper is farmers' adoption behavior of the new agricultural technology extension mode in the formal investigation, which is reflected by whether farmers use the agricultural technology WeChat public account or agricultural technology extension app. When farmers use one of the platforms to obtain agricultural technology information, they are considered to adopt the new agricultural technology extension mode with a value of 1. When farmers do not use any of the platforms to obtain agricultural technology information, they are considered to not adopt the new agricultural technology extension mode, and the value is 0.

3.2.3. Control variables

To ensure the accuracy of the estimation results when using PSM to estimate the processing effects, it is necessary to include as many covariates as possible of those that affect the processing group's acceptance processing and the processing results after acceptance as the control variables. Based on relevant research results (Theis et al., 2018; Yigezu et al., 2018; Ragasa and Mazunda, 2018; Zeweld et al., 2016), this study includes head of household characteristics (gender; age; level of education; risk preference), resource endowment characteristics (farmland; the quality of farmland; farmland, scale, and labor force, family financial conditions), technical features (perceived ease of use; perceived usefulness), social networks (available cooperatives; the relationship with the village cadres; gift spending), cognitive environment characteristics (environmental knowledge and environmental change perception) and Internet access characteristics (daily online time). Seventeen variables serve as the control variables that affect farmers' technology adoption behavior. The values of each control variable are shown in Table 1.

3.3. Data sources and descriptive statistics

3.3.1. Data sources

This study used Shandong Province and Henan Province for the investigation. These provinces were chosen because, first, Henan and Shandong provinces are important agricultural production bases in China, accounting for 17.31% of the country's total grain output.[3] Second, the farmland in the two provinces has low nitrogen/phosphorus, resulting in serious soil and water loss, and the land quality is in urgent need of improvement (Gao et al., 2017c). Third, both provinces have a severe shortage of water in the north. Henan and Shandong provinces rank 26th and 29th, respectively, in terms of per capita water resources, with 354.83 and 222.59 cubic meters per person, respectively.[4] Fourth, the two provinces are prone to frequent outbreaks of diseases and insect pests, and the situation of disease and insect pest control is grim (Gao et al., 2018).

The investigation was conducted in two stages. The first stage was the pre-survey. In June 2018, 10 farmers in each province were randomly selected for household interviews to obtain a preliminary understanding of the adoption of new agricultural technology extension modes and technology adoption. According to the pre-survey results, deficiencies in the questionnaire were improved. The second stage was the formal investigation. From July to September 2018, a stratified random sampling method was adopted. First, according to the level of economic development, each prefecture-level city in Shandong Province and Henan Province was divided into three layers, high, medium and low, and two prefecture-level cities were randomly selected from each layer. Second, 4 counties (cities and districts) were randomly selected in each prefecture-level city. Finally, 17 farmers were randomly selected from each county (city, district). In consideration of the farmers' educational level, this paper adopted the method of investigator interviews to complete the questionnaires. The investigators were trained graduate students and senior undergraduates. A total of 816 questionnaires were distributed, and 759 valid questionnaires were obtained after missing key information and obviously incorrect questionnaires were filtered out, for an effective rate of 93.01%.

3.3.2. Descriptive statistics

As seen in Table 1, the adoption rates of the sample farmers for soil testing and formulated fertilization technology, water-saving irrigation technology and green control techniques were 32.4%, 27.8% and

[3] source: Announcement of the National Bureau of Statistics on grain output

(*footnote continued*)
in 2017, http://www.stats.gov.cn/tjsj/zxfb/201712/t20171208_1561546.html.

[4] source: China Statistical Yearbook –2017, http://www.stats.gov.cn/tjsj/ndsj/2017/indexch.htm.

Table 1
Descriptive statistical analysis of variables.

Variable types	Variable name	Values	Mean	Standard deviation
Explained variable	Adoption behavior of soil testing and formulated fertilization technology	Adopted = 1, not adopted = 0	0.324	0.468
	Adoption of water-saving irrigation technologies	Adopted = 1, not adopted = 0	0.278	0.451
	Adoption of green control techniques	Adopted = 1, not adopted = 0	0.283	0.448
Core explanatory variable	Adoption of new agricultural technology extension mode	Adopted = 1, not adopted = 0	0.153	0.360
Control variables	Gender	Male = 1, female = 0	0.777	0.416
	Age	Actual age in 2018	54.893	6.910
	Level of education	Education years	7.729	2.889
	Degree of risk acceptance	Very risk averse = 1 … Very risk preferring = 7	3.813	1.804
	Farmland scale	Actual farmland area (mu)	14.920	9.546
	Farmland quality	Very low = 1 … Very high = 7	4.119	1.728
	Degree of fragmentation of farmland	Amount of farmland (blocks)	1.588	0.803
	Workforce	Actual household labor force (person)	3.614	1.448
	Financial situation	Very short = 1 … Abundant = 7	3.436	1.967
	Perceived ease of use	Very difficult = 1 … Pretty easy = 7	4.018	1.678
	Perceived usefulness	It does not work at all = 1 … Is very useful = 7	4.004	1.711
	Cooperative participation	Add = 1, not add = 0	0.411	0.492
	Relationship with village cadres	Very bad = 1 … Pretty good = 7	4.489	1.550
	Money spending	Amount of gift money disbursed within one year ($100)	52.016	23.237
	Cognition of environmental knowledge	Very low = 1 … Very high = 7	4.112	1.591
	Environmental change perception	Very weak = 1 … Pretty strong = 7	3.984	1.441
	Daily online time	Average daily online time last month (hours)	3.777	2.833

28.3%, respectively. The adoption rates for technology were relatively low as a whole. The proportion of sample farmers who adopted the new agricultural technology extension mode was 15.28%.

With regard to the sex of the head of household, 77.73% of the heads of household were male. With regard to age composition, the majority of farmers were aged 55–65 years, accounting for 49.54%. With regard to the degree of education, heads of household who had received less than 9 years of education were the most frequently occurring, accounting for 62.85%. With regard to the scale of farmland, the proportion of farmers with less than 10 mu was 42.21%, and the proportion of farmers with 10 mu or more was 57.79%. In terms of the number of people in the labor force in the household, 3–4 people was most common, accounting for 64.16%. In terms of the above indicators, the results of this survey are largely consistent with the results of the Third National Agricultural Census, and the survey samples are representative to a certain extent.[5]

Table 2 presents a comparative analysis of the characteristics of the farmers. As shown in Table 2, significant differences exist in the adoption rates between UF and NUF (regardless of whether the same village has UF) in terms of soil testing and formulated fertilization technology, water-saving irrigation technology and green control techniques. The adoption rates of the three technologies by farmers are significantly higher than the rates of NUF. At the same time, a significant difference exists between some observable control variables of UF and NUF (regardless of whether the same village has UF). For example, UF are younger, have more education, and have a greater acceptance of risk. The scale of farmland of UF is larger, the quality of farmland is better, the degree of farmland fragmentation is lower, and the capital situation is better. UFs' perceived ease of use and perceived usefulness of technology are stronger. Furthermore, the proportion of UF who join cooperatives is higher, as is their expenditure of gift money. UF have a higher level of cognition of environmental knowledge and spend more time online each day.

4. Estimation results

4.1. Direct effects of the new agricultural technology extension mode

In this article, the probit model was first used to estimate the determinants of farmers' adoption of the new agricultural technology extension mode, and the corresponding predicted value was used as the propensity score of farmers' adoption of the new agricultural technology extension mode. As shown in Table 3, with the exception of gender, other variables significantly affected farmers' adoption behavior of new agricultural technology promotion methods. The possible reasons are as follows. First, younger household heads tend to have a higher education level and higher risk preference, to be more receptive to new things, and more easily adopt the new agricultural technology promotion method (Murage et al., 2015). Second, farmers with a larger scale of cultivated land tend to have better-quality cultivated land, place more emphasis on agricultural production, and have more incentive to adopt new agricultural technology promotion methods (Kpadonou et al., 2017). The higher the degree of fragmentation of cultivated land, the more often farmers choose extensive agricultural operation and the less incentive they have to adopt new agricultural technology promotion methods (Geng et al., 2017). Third, the larger the labor force, the wider the channels are for farmers to learn about new agricultural technology promotion methods and the more likely they are to adopt these methods (Gao et al., 2019a). Fourth, the better the family's financial situation, the more able they are to buy computers and smart phones; that is, the more opportunities they have to access new agricultural technology promotion methods (Nigussie et al., 2017). Fifth, the higher the perceived ease of use and usefulness of technology, the more inclined farmers are to adopt new methods of agricultural technology promotion to master technology (Verma and Sinha, 2018). Sixth, farmers who join cooperatives can receive more training in new methods of agricultural technology promotion (Ma and Abdulai, 2016). Seventh, village cadres usually have a better understanding of new things. The better the relationship between farmers and village cadres is, the easier it is for farmers to obtain information about new methods of agricultural technology promotion (Huang et al., 2018). Eighth, the more gift money is spent, the wider the social relation network of farmers will be. With the help of a broad relation network, farmers have the opportunity to obtain more information about new agricultural technology promotion methods (Hunecke et al., 2017). Ninth, the

[5] China's Third National Agricultural Census Major Data Bulletin (no. 5). http://www.gov.cn/xinwen/2017-12/16/content_5247683.htm December 16, 2017.

Table 2
Comparative analysis of characteristics of farmers.

	UF (N = 116)	NUF (new mode farmers are present in the same village) (N = 273)	NUF (farmers who do not use the new mode are present in the same village) (N = 370)	t_1	t_2
Adoption behavior of soil testing and formulated fertilization technology	0.759	0.308	0.197	8.983***	12.988***
Adoption of water-saving irrigation technologies	0.595	0.286	0.173	5.998***	9.697***
Adoption of green control techniques	0.603	0.278	0.186	6.348***	9.411***
Gender	0.784	0.802	0.754	−0.396	0.669
Age	49.517	56.623	55.303	−9.103***	−9.246***
Level of education	8.483	7.842	7.408	1.921*	3.677***
Degree of risk acceptance	4.345	3.861	3.611	2.479**	3.834***
Farmland scale	17.241	14.604	14.424	2.465**	2.729***
Farmland quality	4.534	4.147	3.968	2.065**	3.027***
Degree of fragmentation of farmland	1.319	1.612	1.654	−3.286***	−4.118***
Workforce	3.681	3.659	3.559	0.124	0.778
Financial situation	4.017	3.476	3.224	2.476**	3.715***
Perceived ease of use	4.586	4.011	3.846	3.108***	4.089***
Perceived usefulness	4.466	4.029	3.841	2.311**	3.351***
Cooperative participation	0.586	0.443	0.332	2.596***	4.996***
Relationship with village cadres	4.526	4.495	4.473	0.201	0.301
Money spending	55.862	55.678	48.108	0.072	3.118***
Cognition of environmental knowledge	4.534	4.183	3.927	2.095**	3.449***
Environmental change perception	4.078	4.026	3.924	0.319	0.992
Daily online time	4.689	3.934	3.402	2.353**	4.437***

Note: t_1 is the *t*-test of the difference between UF and NUF (with new mode farmers present in the same village); t_2 is the *t*-test of the difference between UF and NUF (with farmers who do not use the new mode present in the same village); *, ** and *** indicate significance at the statistical levels of 10%, 5% and 1%, respectively.

Table 3
Propensity score estimation results.

Variables	Coefficient	Standard error	Variables	Coefficient	Standard error
Gender	0.377	0.259	Perceived ease of use	0.036***	0.011
Age	−0.053**	0.026	Perceived usefulness	0.102**	0.041
Level of education	1.624**	0.713	Cooperative participation	0.279***	0.099
Degree of risk acceptance	1.829**	0.887	Relationship with village cadres	0.283**	0.142
Farmland scale	0.071*	0.037	Money spending	0.056*	0.029
Farmland quality	0.415***	0.168	Cognition of environmental knowledge	0.162*	0.091
Degree of fragmentation of farmland	−0.319**	0.130	Environmental change perception	0.188*	0.112
Workforce	0.008**	0.004	Daily online time	1.554***	0.562
Financial situation	0.133***	0.047			

Note: *, ** and *** indicate significance at the statistical levels of 10%, 5% and 1%, respectively.

higher farmers' awareness of environmental knowledge and environmental change is, the more actively they acquire technical information that can improve the ecological environment through new agricultural technology promotion (Gao et al., 2019b; Ronner et al., 2018). Tenth, the more time farmers spend daily on the Internet, the more strongly they feel about the Internet's remote services, high efficiency, convenience, personalized interaction and other characteristics, and the more likely they will be to adopt new agricultural technology promotion methods (Rana et al., 2016). The reason gender is not significant is that the gender of most the household heads among the sample farmers was male, and the control effect of the gender of the household head on the model is not obvious.

Balanced control variables are an important prerequisite for the application of PSM; that is, after matching, the control group and the treatment group should not have significant differences in other control variables except for the differences in the behavior of the new agricultural extension method. Table A.1 and Table 4 present the balance test results of the control variables before and after matching. Before matching, all control variables were significantly different (Table 2). After matching, the *t*-test results in Table 4 show that no significant differences existed between the control variables of UF and NUF (with farmers who did not use the new mode present in the same village).[6]

[6] See Table A.1 for details.

Table 4
Matching control variable balance test results before and after.

Mean standard deviation (%)		Pseudo - R^2		P value of the LR statistic	
Before the match	After the match	Before the match	After the match	Before the match	After the match
24.8	6.1	0.227	0.051	0.000	0.861

Note: the results shown in Appendix 1 and Table 4 are the results of matching the adopted equation control variables of soil testing and formulated fertilization technology with the kernel matching method (bandwidth 0.03). The results before and after the matching of adopted equation control variables of other technologies also have a good matching effect, which is not reported to save space.

At the same time, as shown in Table 4, the mean standard deviation of the control variable decreased from 24.8% to 6.1%, and Pseudo-R^2 was used to measure the goodness of fit of the propensity score equation.[2] The value was very low after the match. The p value of the likelihood ratio test indicates that the coefficient of the control variable before matching was significant in combination, whereas the null hypothesis that the coefficient of the control variable is 0 could not be rejected after matching. That is, after matching, the control variable could not determine whether a farmer would adopt the new

Table 5
Average treatment effect (ATT) and sensitivity analysis of the new agricultural technology extension mode to farmers' adoption of technology.

Matching method	Soil testing and formulated fertilization technology	Water-saving irrigation technology	Green control techniques
Core matching (bandwidth 0.03)	0.199***(0.071) [1.3–1.4]	0.118*(0.061) [1.3–1.5]	0.168***(0.062) [1.6–1.9]
Kernel matching (bandwidth 0.06)	0.203***(0.074) [1.3–1.4]	0.124**(0.059) [1.5–1.7]	0.177***(0.063) [1.6–1.9]
Nearest neighbor element matching (1 neighbor element)	0.217***(0.066) [2.1–2.3]	0.081 (0.055)	0.132*(0.069) [2.1–2.3]
Nearest neighbor element matching (5 neighbor elements)	0.205***(0.062) [1.3–1.6]	0.133**(0.057) [1.3–1.5]	0.187**(0.073) [1.7–1.9]

Note: the standard error (200 repetitions) obtained by the bootstrap method is in brackets, and the upper bound of Rosenblum's bound at the 5% statistical level is in brackets; *, ** and *** are significant at the statistical levels of 10%, 5% and 1%, respectively.

agricultural technology extension mode. The above test results show that the dominant deviation of observable variables between the treatment group and the control group was basically eliminated after PSM, and UF and NUF were well matched.

The direct effect estimation results of the new agricultural technology extension mode are shown in Table 5. In the PSM estimation, the standard errors of the estimated results are obtained by the bootstrap method. In this paper, 20, 100, 200, 300 and 500 tests were conducted. The standard error obtained through the bootstrap process of 50 times and 100 times was not stable, but the standard error obtained through tests of 200 times and above was stable. This paper reports only the standard error estimation results obtained from the bootstrap process 200 times. Four match methods used to estimate results showed that the new agricultural technology extension mode for farmers to adopt soil testing and formulated fertilization technology and water-saving irrigation technology had a significant role in promoting prevention and green control techniques; that is, the proportion of farmers who adopted the soil testing and formulated fertilization technology, water-saving irrigation technology and green control techniques, respectively, to farmers who did not use the new agricultural technology extension mode were as follows: 19.9%–21.7%, 11.8%–13.3% and 13.2%–13.3%.

The reliability of the PSM estimation results of processing effects depends on whether the processing effects are accepted and is not completely determined by observable variables. However, if there is an effect of unobservable variables in the processing effects, the deviation will be hidden, and it will have an impact on the robustness of the estimation results. In this paper, the Rosenblum boundary is used to analyze the influence of the processing effect on the estimation results if part of the processing effect is determined by unobservable variables. Sensitivity analysis has no significance for the lower bound of the Rosenbaum limit that emphasizes and underestimates insignificant processing effects (Rosenbaum, 2002). In this analysis, if unobservable variables are present, the influence of the new agricultural technology extension mode on UF technology will be overestimated, so only the upper bound of Rosenblum's boundary is calculated. As shown in Table 5, the significant positive influence of the new agricultural technology extension on UF technology is not sensitive to hidden deviation. The upper bound of Rosenbaum's boundary ranges from 1.3 to 2.3; that is, under the condition that only existing control variables are controlled, when the hidden deviation makes the behavior of farmers who adopt the new agricultural technology extension mode 30% higher, the estimated result of the average processing effect of the new agricultural technology extension mode on farmers' adoption of technology will become insignificant. Since this study controls the corresponding control variables that affect farmers' adoption of the new agricultural technology extension mode and agricultural technology adoption, the probability of this higher value occurring is small. Therefore, the estimation results of the average processing effect of the new agricultural technology extension mode on UF's adoption of new agricultural technology are considered relatively robust.

To further verify the robustness of the PSM estimation results, this paper took the average daily online time (hours) of other sample farmers in the same county as the instrumental variable and used the instrumental variable method to test robustness. The reasons are as follows. First, the instrumental variable reflects the general situation of Internet popularization in the county. Farmers in the same county share the same Internet popularization basis in adopting the new agricultural technology extension mode. Therefore, the instrumental variable will have a direct impact on farmers' adoption behavior of the new agricultural technology extension mode. Second, the instrumental variables are exogenous, and there is no direct relationship between the instrumental variables excluding specific sample information and the sample farmers' adoption of agricultural technology.

The average daily online time (hours) of other sample farmers in the same county was taken as the instrumental variable of the adoption behavior of the new agricultural technology extension mode. The predictive value of farmers' adoption behavior of the new agricultural technology extension mode based on the instrumental variable was obtained by the first-stage probit regression. On this basis, the predicted value of farmers' adoption behavior of the new agricultural technology extension mode was substituted into the second-stage regression as the proxy index to investigate its effect on farmers' adoption behavior of agricultural technology. It can be seen from the estimation results in the first stage of Table 6 that the endogenous test parameter atanhrho_12 is significant at confidence levels of 1%, 5% and 1%, indicating that the adoption behavior of the new agricultural technology extension mode

Table 6
Estimation results of instrumental variables.

	Soil testing and formulated fertilization technology		Water-saving irrigation technology		Green control techniques	
	First stage	Second stage	First stage	Second stage	First stage	Second stage
The adoption of new agricultural technology extension mode	–	0.261*** (0.099)	–	0.236** (0.117)	–	0.250*** (0.096)
Average daily online time (hours) of other sample farmers in the same county	0.571*** (0.051)	–	0.504*** (0.038)	–	0.559*** (0.047)	–
Control variables	Under control	Under control	Under control	Under control	Under control	Under control
atanhrho_12	0.814*** (0.235)	–	0.776** (0.376)	–	0.827*** (0.224)	–

Note: *, ** and *** represent significance at the confidence levels of 10%, 5% and 1%, respectively. The values in brackets are robust standard errors.

Table 7
Spillover effects of the new agricultural technology extension mode.

Matching method	Soil testing and formulated fertilization technology	Water-saving irrigation technology	Green control techniques
Average treatment effect (ATT) of the new agricultural technology extension mode on the technical adoption of UF compared with that of NUF (with new mode farmers present in the same village)			
Core matching (bandwidth 0.03)	0.132 (0.084)	0.147 (0.091)	0.177**(0.068)
Kernel matching (bandwidth 0.06)	0.134 (0.087)	0.151 (0.094)	0.163*(0.089)
Nearest neighbor element matching (1 neighbor element)	0.126 (0.077)	0.143 (0.088)	0.238**(0.091)
Nearest neighbor element matching (5 neighbor elements)	0.117 (0.073)	0.149 (0.094)	0.212***(0.051)
The average treatment effect (ATT) of the new agricultural technology extension mode on the technology adoption of NUF (with new mode farmers present in the same village) compared with NUF (with new mode farmers in the same village)			
Core matching (bandwidth 0.03)	0.058**(0.028)	0.069**(0.034)	0.036 (0.073)
Kernel matching (bandwidth 0.06)	0.053**(0.021)	0.065*(0.037)	0.033 (0.071)
Nearest neighbor element matching (1 neighbor element)	0.044***(0.017)	0.052**(0.024)	0.027 (0.065)
Nearest neighbor element matching (5 neighbor elements)	0.041***(0.014)	0.050**(0.022)	0.026 (0.075)

Note: the standard error (200 repetitions) obtained through the bootstrap method is in brackets; *, **, and *** are significant at the statistical levels of 10%, 5% and 1%, respectively.

in the regression is the endogenous variable and that there is no problem of weak instrumental variables. The second phase estimation results show that adoption behavior of the new agricultural technology extension mode and the adoption behavior for soil testing and formulated fertilization technology, water-saving irrigation technology, and green control techniques is 1%, 5% and 1%, respectively, and the confidence level of significance is positive. The estimated results are consistent with the tendency of PSM, which shows that the results are sound.

4.2. Spillover effects of the new agricultural technology extension mode

To estimate the spillover effect of the new agricultural technology extension mode, the matching analysis was conducted on two groups of NUF (regardless of whether others in the same village were UF). At the same time, a matching analysis was performed between UF and NUF (with new mode farmers present in the same village) for comparison. As shown in Table 7, compared with NUF (with new mode farmers present in the same village), the new agricultural technology extension mode had a significant extension effect on the adoption of green control techniques by farmers, and the probability of adopting this technology by farmers was 16.3%–21.2% higher than that of NUF (with new mode farmers present in the same village). However, the impact of the new agricultural technology extension mode on the adoption of soil testing and formulated fertilization technology and water-saving irrigation technology was not significant.

When UF (with farmers who did not use the new mode in the same village) were compared to NUF, the average treatment effect of the new agricultural technology extension mode on the adopted soil testing and formulated fertilization technology and water-saving irrigation technology was significant, but the average treatment effect on adopted green control techniques was not significant. This finding shows that the new agricultural technology extension mode promotes the adoption of soil testing and formulated fertilization technology and water-saving irrigation technology by NUF (when new mode farmers are in the same village) but does not promote the adoption of green control techniques.

For the direct effect analysis of the new agricultural technology extension mode, this study estimated the results and found that the new agricultural technology extension mode improved the UF technology adoption level. Among NUF (with new mode farmers present in the same village), the measurements showed that the adoption of soil testing and formulated fertilization technology and water saving irrigation technology had a spillover effect, but the adoption of green control techniques did not show a similar spillover effect. The reason may be that compared with the other two technologies, green control techniques are a complex technology set with higher knowledge intensity (Gao et al., 2017b). UF can improve their adoption level, but due to their limited knowledge and skills, they find it difficult to give effective guidance to NUF (when new mode farmers are present in the same village). At the same time, the complexity of the technology requires more time and energy for UF to guide NUF (when new mode farmers are in the same village), and UF themselves lack the incentive to give technical guidance to NUF (when new mode farmers are in the same village).

4.3. The distribution effect of the new type of agricultural technology extension

The estimated results are shown in Table 8 and Table 9. The impact of the new agricultural technology extension on the technical adoption of farmers varies with the age of farmers and the size of farmland.

First, with regard to the direct effect, the new agricultural technology extension mode has a significant positive impact on elderly and small-scale UF using soil testing and formulated fertilization technology, water-saving irrigation technology and green control techniques, but it does not have a significant impact on young and middle-aged farmers, medium-sized farms, and the abovementioned UF. This means that older and small-scale farmers will benefit more from new forms of agricultural extension.

Second, from the perspective of spillover effects, soil testing and formulated fertilization technology and water saving irrigation technology have been made available in a new agricultural technology extension mode for elderly and small-scale NUF (with new mode farmers present in the same village). Technology adoption shows a significant positive influence, but for young and middle-aged farmers, farms above medium size and NUF (with new mode farmers present in the same village) have no obvious effect on technology adoption. This finding suggests that older and small-scale NUF (with new mode farmers present in the same village) have more of a spillover effect from the new agricultural technology extension mode.

In conclusion, both the direct effect and the spillover effect of the new agricultural technology extension mode play a greater role in promoting technical adoption by elderly and small-scale farmers; thus, hypothesis 3 is verified. The reason may be that compared with middle-aged and young farmers and farmers of medium scale and above, elderly and small-scale farmers are limited by their own endowments and lack the ability to acquire and adopt information about new technologies (Grabowski et al., 2016). The adoption of the new agricultural

Table 8
Distributional effect of new agricultural technology extension mode 1.

	Age	ATT Nuclear match (bandwidth 0.06)	ATT Nearest neighbor element matching (5 adjacent elements)
The direct effect of the new agricultural technology extension mode on the technical adoption of farmers of different ages			
Soil testing and formulated fertilization technology	Elderly farmers (head of household aged over 60)	0.121***(0.043)	0.120***(0.041)
	Young and middle-aged farmers (head of household aged 60 or below)	0.123 (0.076)	0.126 (0.077)
Water-saving irrigation technology	Elderly farmers (head of household aged over 60)	0.106**(0.052)	0.118***(0.044)
	Young and middle-aged farmers (head of household aged 60 or below)	0.114 (0.071)	0.122 (0.075)
Green control techniques	Elderly farmers (head of household aged over 60)	0.118**(0.057)	0.111**(0.047)
	Young and middle-aged farmers (head of household aged 60 or below)	0.124 (0.087)	0.113 (0.083)
Spillover effects of new agricultural technology extension mode on technology adoption by farmers of different age groups			
Soil testing and formulated fertilization technology	Elderly farmers (head of household aged over 60)	0.119**(0.040)	0.117***(0.039)
	Young and middle-aged farmers (head of household aged 60 or below)	0.102 (0.079)	0.109 (0.081)
Water-saving irrigation technology	Elderly farmers (head of household aged over 60)	0.105*(0.055)	0.101**(0.041)
	Young and middle-aged farmers (head of household aged 60 or below)	0.111 (0.096)	0.116 (0.085)

Note: the standard error (200 repetitions) obtained through the bootstrap method is in brackets; *, ** and *** are significant at the statistical levels of 10%, 5% and 1%, respectively.

technology extension mode can marginally improve their ability to adopt new technologies. However, young and middle-aged farmers and farmers of medium-scale farms and above have a strong ability to acquire and adopt new technology information, but the improvement of their ability to adopt new technology by adopting new agricultural technology extension modes is limited.

5. Conclusions and policy recommendations

Based on survey data of 759 farmers in Shandong Province and Henan Province, this paper uses PSM to explore the direct effect, spillover effect and distributional effect of a new agricultural technology extension mode on the technical adoption behavior of farmers. The results show that the new agricultural technology extension mode somewhat improves the level of technical adoption of farmers with a partial spillover effect, and farmers of different ages and with different scales of operation benefit differently from the technology extension. The direct effect of the new agricultural technology extension mode shows that compared with NUF (with farmers who do not use the new mode in the same village), the new agricultural technology extension mode significantly improves the adoption level of the soil testing and formulated fertilization technology, water-saving irrigation technology and green control techniques of UF. The spillover effect of the new agricultural technology extension mode shows that in comparison with NUF (with farmers who do not use the new mode in the same village), the new extension mode is not significantly increased. NUF (with new mode farmers in the same village) increase their level of adoption of soil testing and formulated fertilization technology and water-saving irrigation technology, but the new extension model does not significantly enhance the adoption of green control techniques. The distribution of

Table 9
Distributional effect of new agricultural technology extension mode 2.

	Farmland scale	ATT Kernel matching (bandwidth 0.06)	ATT Nearest neighbor element matching (5 neighbor elements)
The direct effect of the new agricultural technology extension mode on the technical adoption of farmers with different scale of farmland			
Soil testing and formulated fertilization technology	Small size (10 mu or less)	0.132**(0.054)	0.131**(0.051)
	Medium size and above (over 10 mu)	0.134 (0.087)	0.137 (0.088)
Water-saving irrigation technology	Small size (10 mu or less)	0.126***(0.047)	0.133*(0.069)
	Medium size and above (over 10 mu)	0.117 (0.071)	0.128 (0.079)
Green control techniques	Small size (10 mu or less)	0.135**(0.060)	0.113*(0.068)
	Medium size and above (over 10 mu)	0.129 (0.081)	0.122 (0.074)
Spillover effects of new agricultural technology extension mode on technology adoption of farmers with different scale of farmland			
Soil testing and formulated fertilization technology	Small size (10 mu or less)	0.131***(0.045)	0.106*(0.056)
	Medium size and above (over 10 mu)	0.121 (0.075)	0.127 (0.078)
Water-saving irrigation technology	Small size (10 mu or less)	0.118**(0.049)	0.123***(0.040)
	Medium size and above (over 10 mu)	0.125 (0.099)	0.130 (0.088)

Note: the standard error (200 repetitions) obtained through the bootstrap method is in brackets; *, ** and *** are significant at the statistical levels of 10%, 5% and 1%, respectively.

the new agricultural technology extension mode shows an effect when compared with NUF (with farmers who do not use the new mode present) in that the measures for the new agricultural technology extension mode for elderly and small-scale UF positively affected the adoption of soil testing and formulated fertilization technology and water-saving irrigation technology and had a significant positive influence on prevention and green control techniques. For elderly farmers and NUF, not including small-scale NUF (with new mode farmers present in the same village), there was a significant positive influence on soil testing and formulated fertilization and water saving irrigation technology, but for young and middle-aged UF, farmers with middle-sized farms and above and NUF (with farmers using the new mode present in the same village), no obvious effect of technology adoption was observed.

Based on the research conclusions of this paper, the following policy implications can be drawn. First, the government should pay more attention to new agricultural technology extension modes and guide farmers to adopt these modes by means of active publicity, organizing training and issuing coupons for agricultural materials on platforms. Second, for agricultural technologies with high knowledge intensity, agricultural technology WeChat public accounts, agricultural technology extension apps and other platforms should further improve the quality of the articles and videos used to strengthen two-way interaction with farmers and effectively improve their technical knowledge. On the other hand, to encourage UF to spread technical knowledge and information to NUF, corresponding incentive measures should be considered. Third, given that elderly and small-scale farmers benefit most from the new agricultural technology extension mode, directing publicity to farmers of older age and on smaller farms and paying more attention to the collection of feedback from these two types of farmers on improving service can improve the efficiency of the extension of new agricultural technology extension modes.

CRediT authorship contribution statement

Yang Gao: Conceptualization, Methodology, Validation, Investigation, Writing - review & editing. **Duanyang Zhao:** Data curation, Formal analysis, Writing - original draft. **Lili Yu:** Investigation, Writing - review & editing. **Haoran Yang:** Writing - review & editing.

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Appendices

Table A.1
Matching control variable balance test results before and after.

	UF (N = 116)	NUF (with farmers who do not use the new mode present in the same village) (N = 370)	t
Gender	0.755	0.752	0.221
Age	44.885	45.104	−0.198
Level of education	7.617	7.582	0.345
Degree of risk acceptance	3.826	3.811	0.107
Farmland scale	8.314	8.297	0.235
Farmland quality	4.175	4.088	0.366
Degree of fragmentation of farmland	1.580	1.581	−0.008
Workforce	3.598	3.583	0.214
Financial situation	3.441	3.399	0.356
Perceived ease of use	4.019	4.019	0.000
Perceived usefulness	3.989	3.988	0.002
Cooperative participation	0.410	0.391	0.084
Relationship with village cadres	4.588	4.579	0.066
Money spending	50.571	49.872	0.883
Cognition of environmental knowledge	4.109	4.052	0.286
Environmental change perception	3.968	3.967	0.001

Note: *, ** and *** mean that *t*-test results of UF and NUF (with farmers who do not use the new mode present in the same village) are significant at the statistical levels of 10%, 5% and 1%, respectively.

References

Altalb, A.A.T., 2017. Farmers' knowledge towards the role of extension services in agricultural development in Opolski county, Lubelskie province of Poland. Asian J. Agric. Extens. Econ. Sociol. 15 (3), 1–8.
Gao, Y., Li, P., Wu, L., Lu, J., Yu, L., Yin, S., 2018. Preferences of for-profit pest control firms on support policy in China. J. Clean. Prod. 181, 809–818.
Gao, Y., Niu, Z.H., Yang, H.R., Yu, L.L., 2019a. Impact of green control techniques on family farms' welfare. Ecol. Econ. 161, 91–99.
Gao, Y., Zhang, X., Wu, L., Yin, S., Lu, J., 2017a. Resource basis, ecosystem and growth of grain family farm in China: based on rough set theory and hierarchical linear model. Agric. Syst. 154, 157–167.
Gao, Y., Zhang, X., Lu, J., Wu, L., Yin, S., 2017b. Adoption behavior of green control techniques by family farms in China: evidence from 676 family farms in Huang-huai-hai Plain. Crop Protect. 99, 76–84.
Gao, Y., Zhao, D.Y., Yu, L.L., Yang, H.R., 2019b. Duration analysis on the adoption behavior of green control techniques among Chinese farms. Environ. Sci. Pollut. Control Ser. 26 (7), 6319–6327.
Gao, Y., Wang, N., Li, X., Wang, Y., 2017c. Adoption of eco-friendly soil management practices by smallholder farmers in Shandong of China. Issues Agric. Econ. 38 (1) 38-47 +110-111.
Geng, Y., Zheng, S., Lu, Q., 2017. Impact of economic incentives and social networks on farmers' adoption of integrated pest management technology——evidence from the kiwifruit main production areas of Shaanxi province. J. Huazhong Agric. Univ. (Soc. Sci. Ed.) 132 (6), 59–69.
Grabowski, P.P., Kerr, J.M., Haggblade, S., Kabwe, S., 2016. Determinants of adoption of minimum tillage by cotton farmers in eastern Zambia. Agric. Ecosyst. Environ. 231, 54–67.
Gu, J., 2013. Agricultural technology extension based on mobile Internet technology service 'the last kilometer'. Prim. Agric. Technol. Extens. 1 (11), 8–9.
Heckman, J.J., Ichimura, H., Todd, P.E., 1997. Matching as an econometric evaluation estimator: evidence from evaluating a job training program. Rev. Econ. Stud. 64 (4), 605–654.
Huang, W., Zhao, T., Tong, D., 2018. Farmers' adoption of environmentally friendly agricultural technologies from a multi-technology perspective. Jiangsu Agric. Sci. 46 (14), 329–333.
Hunecke, C., Engler, A., Jara-Rojas, R., Poortvliet, M., 2017. Understanding the role of social capital in adoption decisions: an application to irrigation technology. Agric. Syst. 153, 221–231.
Kpadonou, R.A.B., Owiyo, T., Barbier, B., Denton, F., Rutabingwa, F., Kiemad, A., 2017. Advancing climate-smart-agriculture in developing drylands: joint analysis of the adoption of multiple on-farm soil and water conservation technologies in West African Sahel. Land Use Pol. 61, 196–207.

Li, J., Zhang, Y., Cui, B., 2018. 'Internet +' is used to promote the upgrading of agricultural technology extension mode. Prim. Agric. Technol. Extens. 6 (1), 7–8.
Liu, Y., Peng, C., 2017. 'Learn to farm' APP helps promote agricultural technology services. Agric. Netw. Inf. 9, 72–76.
Ma, W., Abdulai, A., 2016. Does cooperative membership improve household welfare? Evidence from apple farmers in China. Food Pol. 58, 94–102.
Murage, A.W., Midega, C.A.O., Pittchar, J.O., Pickett, J.A., Khan, Z.R., 2015. Determinants of adoption of climate-smart push-pull technology for enhanced food security through integrated pest management in Eastern Africa. Food Secur. 7 (3), 709–724.
Nakano, Y., Tsusaka, T.W., Aida, T., Pede, V.O., 2018. Is farmer-to-farmer extension effective? The impact of training on technology adoption and rice farming productivity in Tanzania. World Dev. 105, 336–351.
Nigussie, Z., Tsunekawa, A., Haregeweyn, N., Adgo, E., Nohmi, M., Tsubo, M., Aklog, D., Meshesha, D.T., Abele, S., 2017. Factors influencing small-scale farmers' adoption of sustainable land management technologies in north-western Ethiopia. Land Use Pol. 67, 57–64.
Rana, N.P., Dwivedi, Y.K., William, M.D., Weerakkody, V., 2016. Adoption of online public grievance redressal system in India: toward developing a unified view. Comput. Hum. Behav. 59, 265–282.
Ragasa, C., Mazunda, J., 2018. The impact of agricultural extension services in the context of a heavily subsidized input system: the case of Malawi. World Dev. 105, 25–47.
Ronner, E., Descheemaeker, K., Almekinders, C.J.M., Ebanyat, P., Gillera, K.E., 2018. Farmers' use and adaptation of improved climbing bean production practices in the highlands of Uganda. Agric. Ecosyst. Environ. 261, 186–200.
Rosenbaum, P.R., 2002. Attributing effects to treatment in matched observational studies. J. Am. Stat. Assoc. 97 (457), 183–192.
Rosenbaum, P.R., Rubin, D.B., 1983. The central role of the propensity score in observational studies for causal effects. Biometrika 70 (1), 41–55.
Taylor, M., Bhasme, S., 2018. Model farmers, extension networks and the politics of agricultural knowledge transfer. J. Rural Stud. 64, 1–10.
Theis, S., Lefore, N., Meinzen-Dick, R., Bryan, E., 2018. What happens after technology adoption? Gendered aspects of small-scale irrigation technologies in Ethiopia, Ghana, and Tanzania. Agric. Hum. Val. 35 (3), 671–684.
Tong, D., Huang, W., Ying, R., 2018. The impacts of grassroots Public Agricultural technology extension on Farmers'Technology Adoption: an Empirical Analysis of rice technology demonstration. China Rural Surv. 4, 59–73.
Verma, P., Sinha, N., 2018. Integrating perceived economic wellbeing to technology acceptance model: the case of mobile based agricultural extension service. Technol. Forecast. Soc. Change 126, 207–216.
Wossen, T., Abdoulaye, T., Alene, A., Haile, M.G., Feleke, S., Olanrewaju, A., Manyong, V., 2017. Impacts of extension access and cooperative membership on technology adoption and household welfare. J. Rural Stud. 54, 223–233.
Yao, Z., Ding, T., 2018. Preliminary study on the informatization construction of basic level agricultural technology extension in Changyuan county. Prim. Agric. Technol. Extens. 6 (6), 5–6.
Yigezu, Y.A., Mugera, A., El-Shater, T., Aw-Hassan, A., Piggin, C., Haddad, A., Khalil, Y., Loss, S., 2018. Enhancing adoption of agricultural technologies requiring high initial investment among smallholders. Technol. Forecast. Soc. Change 134, 199–206.
Yin, R., Luo, X., Li, R., Huang, Y., 2018. Under the background of informatization, why do farmers favor agricultural technicians to carry out agricultural technology extension in the field? Res. Agric. Modern. 39 (4), 576–583.
Yin, S., Gao, Y., Wu, L., 2017. Construction of Chinese Food Safety Social Co-governance System: Theory and Practice. People's Publishing House, Beijing, China.
Zeweld, W., Huylenbroeck, G.V., Tesfay, G., Speelman, S., 2016. Smallholder farmers' behavioural intentions towards sustainable agricultural practices. J. Environ. Manag. 187 (1), 71–81.