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Farmers' adoption of agriculture green production technologies: perceived value or policy-driven?

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A R T I C L E I N F O

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A B S T R A C T

Understanding the underlying reasons for farmers' AGPT adoption in the context of resource environment tightening and agricultural carbon reduction has become crucial to promote agriculture sustainable development. This paper uses multiple ordered regression model and probit model to test the impact of farmers' perceived value on their adoption of agricultural green production technologies (AGPT) by using the first-hand data from 613 rice farmers in Hunan, and explores the effect and mechanism of policy subsidies and market incentives on the adoption of AGPT, and investigates the differences in the impact of perceived value on the adoption of green technologies in different production stages. The results showed that, (1)farmers' AGPT adoption is significantly affected by their perceived value, in which perceived benefits significantly promotes farmers' AGPT adoption, while the perceived risks is the opposite. But farmers' AGPT adoption in different production stages is influenced by different perceived value. The adoption of soil testing and fertilization technology (STFT) in the pre-production stage is significantly influenced by the perceived benefits; adoption of green pest control technology (GPCT) in the mid-production stage is significantly influenced by both the perceived benefits and the perceived risks; and adoption of straw return technology (SRT) in the post-production stage is significantly influenced by the perceived risks. (2) Farmers' adoption of green technologies can be encouraged by policy subsidies, which also have the moderating effect of decreasing the negative influence of perceived risks on farmers' adoption behaviour. (3) Further analysis reveals that market incentives can compensate for the limitations of policy subsidies, greatly promote farmers' adoption of AGPT, and regulate farmers' perceived risks and perceived benefits to encourage them to use green technologies. Consequently, the Government should actively publicize and organize training on agriculture green technologies, and provide diversified subsidy programmes for different green technologies. And governments should also improve the quality certification system and the market price mechanism for agricultural products, so as to help farmers adopting green technologies to achieve an increase in their income.

1. Introduction

The traditional agricultural production method with high inputs of chemical fertilizers and pesticides has stabilized China's grain output at more than 650 million tons for eight consecutive years, but it also led to a series of negative externalities, such as degradation

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of arable land, intensification of agricultural non-point source pollution, and reduction of biodiversity, which have constrained the sustainable development of the grain industry [1]. In 2016, the Chinese government officially issued that the agricultural subsidy system must be ecology-oriented, hoping to protect farmland ecosystems through policy subsidies. In 2018, China proposed to promote green production technologies such as soil testing and fertilization technology (STFT) and green pest control technology (GPCT), for the sake of accelerating the process of greening agriculture in China. The popularization and application of green agricultural technology is the key to the green development of agriculture. However, farmers didn't respond positively to green technologies, and the phenomena of low willingness to adopt and low level of application are common in rural China [2]. The no-tillage planting, water-saving irrigation, and straw return technologies, had average utilization rates of 7.27 %, 11.67 %, and 27.36 %, respectively, in China in 2019 [3].

Agricultural green production technology is a general term for a series of technologies to increase production, ecological and environmental protection, and reduce carbon emissions, including conservation tillage technology, STFT, and GPCT [4]. The adoption of AGPT can improve the quality of cultivated land, reduce agricultural pollution, and guarantee the safety of agricultural products [5–7]. However, green technologies are characterized by quasi-public goods with strong positive externalities, and the benefits of farmers' AGPT adoption tend to flow to consumers and suppliers of agricultural products, while the costs of adoption can only be borne by farmers [8,9]. Therefore, it is necessary for the government to utilize financial subsidies and transfer payments to share the cost, or to use market incentives to enhance the expectation of green agricultural products' price, so as to promote the application of AGPT. However, there are serious information asymmetries in agricultural markets, and it is often difficult to sell green agricultural products at high prices, which reduced farmers' earning expectations and inhibited their AGPT adoption. In addition, other studies have found that policy subsidies are universal and non-market-oriented, and can only play a short-term role in stimulating fundamentally environmentally friendly behaviors among farmers [10].

The current influencing factors of farmers' AGPT adoption mainly focus on the following aspects. First, the endowment characteristics of farmers. It has been found that farmers' age, gender, literacy, health status, part-time employment, and the degree of cultivated land fragmentation of farmland can affect the adoption of AGPT [11–14]. Farmers' household income can alleviate the financial constraints of their AGPT adoption, and farmers' literacy level can break the information hindrance of green technology adoption [15,16]. In addition, some scholars found that farmers' social networks can broaden their access to green information technology and enhance farmers' technology awareness, thus promoting technology adoption [14,17]. Second, external environmental factors. Green technologies in agriculture are characterized by high costs and uncertain benefits, and are not more advantageous in promoting grain production. Therefore, policy subsidies can promote farmers' AGPT adoption by compensating their agriculture costs and reducing their perception of technological risks [18,19]. Other scholars have pointed out that the market price of grain is directly related to the costs and benefits of farmers, and if the adoption of AGPT can make the market price and benefits of agricultural products expected to be higher than the cost, farmers will choose to adopt green production technology (Mao et al., 2021; Marenya et al., 2014) [20,21]. In addition, farmers' participation in agricultural extension training and demonstration programs can promote the adoption of AGPT [22,23]. Agricultural socialization services can guide farmers to actively adopt AGPT through farmers' participatory technological innovation [24]. In addition, smallholder farmers joining cooperatives and developing into family farms are also recognized as important factors influencing farmers' AGPT adoption [25].

In addition, scholars have applied theories from psychology and behavior to farmers' sustainable production behavior [26,27]. On the basis of the theory of planned behavior and the theory of motivation, related studies found that farmers' subjective attitudes, behavioral norms, and perceived behavioral control can positively affect farmers' sustainable production behavior [28–31]. Li et al. (2020) [32]found that farmers' AGPT adoption are the result of weighing their perceived benefits of AGPT against perceived risks, and the perceived benefits plays a more critical role than perceived risks on farmers' AGPT adoption.

Existing studies mainly examined the impact of farmers' characteristics and agricultural policies on farmers' AGPT adoption from the perspectives of economics and sociology, and many individualized solutions have been derived from their conclusions, which made it difficult for governmental departments to make trade-offs when formulating policies. Furthermore, while some researchers have recognized the impact of farmers' perceived value on their adoption of AGPT, most of the research uses a single green technologies as the outcome variable and does not provide a comparative analysis of the adoption of AGPT in different production stages, which makes it difficult to formulate precise policy. Furthermore, fewer studies have examined the adoption behavior of green technologies by integrating variables like policy subsidies and farmers' perceived value of the technology.

Therefore, we empirically analyzes the influence of farmers' perceived value on their AGPT adoption by using survey data from 613 rice farmers in Hunan Province. The main contributions are demonstrated as follows: firstly, based on the heterogeneity in agricultural production stages, we selected one representative green technology for each of the three stages of pre-production, mid-production and post-production, namely soil testing and formula fertilization technology, green pest control technology and straw return technology, to measure farmers' AGPT adoption. The impact of farmers' perceived value on their AGPT adoption was examined by using a multiple ordered regression model; and we analyzed the heterogeneity of perceived benefits and perceived risks on farmers' AGPT adoption in different stages by using the probit model. Secondly, We explore the effects of policy subsidies and market incentives on farmers' green production technologies and describe their complementary roles. Thirdly, We also investigate the moderating roles of policy subsidies and market incentives between farmers' perceived value and the adoption of AGPT. Clarifying the above issues is of great practical significance for understanding the deep logic of green technologies adoption by farmers and accelerating the promotion of green production technologies in Chinese agriculture.

2. Theoretical analysis

According to Schulz's "rational smallholder" hypothesis, the goal of farmers' production is to maximize profits, and the adoption of green production technologies will change the existing allocation of agricultural factors of production, thus affecting their family income [33]. Consequently, farmers consider both the potential risks and benefits of adopting green technologies when making decisions about their adoption. The risk of green technologies adoption refers to the potential reduction in grain output due to the improper use of green technologies, as well as the additional production costs of technology adoption. Only when the expected benefits of green technologies adoption by farmers are greater than the risks, farmers will choose to use green technologies in agricultural production. Therefore, the condition for farmers to adopt green production technologies is shown in equation (1).

$$p_1 y_1 + u_1 - c_1 - c \geq p_0 y_0 - c \tag{1}$$

Where p_1 and y_1 denote the price of foods and grain outputs of farmers adopting green technologies, p_0 and y_0 denote the price of foods and grain outputs when farmers don't adopt green technologies, c_1 is the cost of green technologies adoption, such as the expenses of agricultural machinery services that farmers need to pay extra for the adoption of green technologies, c denotes the cost of agriculture production by farmers, and u_1 denotes the potential benefits of green technologies adoption by farmers.

Because China's current agricultural product market price mechanism is not perfect, the prices of foods will not change significantly whether farmers adopt green technologies or not, so we assume that $p_1 = p_0$. In this condition, farmers will choose to adopt green technologies when their inputs and outputs of agriculture production satisfy $p_1(y_1 - y_0) + u_1 - c \geq 0$.However, Farmers are unable to precisely assess the benefits and risks of using green technologies prior to adoption. Before deciding whether to adopt, they can only form an expectation of the benefits and risks of adopting green technologies by observing other people who have used green technologies in their community. Theory of Planned Behavior argues that the individual behavior decisions depend on their behavioral attitudes, and perceived value is the most fundamental reason for the formation of farmers' behavioral attitudes [30,34]. According to the perceived value theory, farmers' AGPT adoption is the result of comparison between farmers' perceived benefits and perceived risks, which means that the adoption of green technologies depends on whether the corresponding economic and ecological values they bring can compensate for the production cost increases [35–38]. As the decision-makers in agricultural management, farmers' production behavior takes maximizing their own profits as the primary goal. Therefore, farmers' expectations of being able to improve economic benefits such as agricultural productivity and agricultural economic output will help them to adopt more environmentally friendly ways in agriculture production [39]. Therefore, we formulate the following hypotheses.

hypothesis 1-1. : Farmers' perceived benefits can significantly promote agricultural green technologies adoption.

hypothesis 1-2. Farmers' perceived risks can significantly inhibit the adoption of agricultural green technologies.

Agricultural green technologies can reduce the negative externalities of environmental pollution caused by excessive use of chemical fertilizers and pesticides, and can also lower pesticide residues in agricultural products to ensure the safety of agricultural products. Therefore, the adoption of AGPT has a strong positive externality, which makes the social value of technology adoption by farmers is greater than their private value, resulting in the willingness and intensity of green technologies adoption by farmers is not high. Therefore, it is difficult to realize the popularization of AGPT only by the independent adoption of farmers, and at this time it is necessary for the government to intervene through taxation, administrative penalties, financial subsidies. The application of green production technology requires farmers to pay more opportunity costs and capital costs. Financial subsidies provided by government can alleviate the financial constraints of farmers, make up for their adoption costs, strengthen the sense of identity of farmers on green production technology, thereby mobilizing the enthusiasm of farmers for green technologies adoption [40]. Li et al. (2022) [41] found that policy subsidies can increase farmers' marginal income and reduce production costs to promote farmers' pro-environmental behaviors. Tian et al. (2022) [42] and Ma et al. (2023) [43] found that ecological compensations and financial subsidies can influence farmers' perceived value of green technologies, reduce farmers' risk expectations, thus promote green production behaviors of farmers. Therefore, we propose the following hypothesis.

Hypothesis 2-1. Policy subsidies can promote green technologies adoption by farmers.

Hypothesis 2-2. Policy subsidies can increase the perceived benefits of AGPT and promote green technologies adoption by farmers.

Hypothesis 2-3. Policy subsidies can reduce farmers' risk perception and promote their AGPT adoption.

The efficient distribution of resources is more successful when the government and market forces work together. Nonetheless, China's agricultural production is fundamentally small-scale and decentralized, and large-scale policy subsidies can easily lead to financial strain. The market price of agricultural products is also an essential factor in determining farmers' AGPT adoption. Farmers who adopt green technologies are likely to get higher profits through price premiums, as consumers are desired to more environment friendly products and are willing to pay a higher eco-premium [44]. This indicates that, the price of food produced by farmers using green technologies is greater than the price of foods produced by farmers not using green technologies, which means. Increased expected economic benefits from the adoption of green production technologies by farmers will promote their green production. However, the fulfillment of this condition must be based on the premise that the market price mechanism for agricultural products is sound. Under the circumstances, market incentives can offset the drawbacks of policy subsidies and serve as a substitute. Therefore, we propose the following hypothesis. The research framework of this paper is shown in Fig. 1.

Hypothesis 3-1. Market incentives can promote green technologies adoption by farmers.

Hypothesis 3-2. Market incentives can increase farmers' perceived benefits of green technologies and promote their adoption.

Hypothesis 3-3. : Market incentives can reduce farmers' risk perception and promote farmers' AGPT adoption.

3. Materials and methods

3.1. Variables definition

3.1.1. Dependent variables

The dependent variable is farmers' AGPT adoption. Due to the differences in whether the respondents adopted and the types of green technologies adopted in the questionnaire survey. Therefore, this paper chooses to take the comprehensive situation of respondents' AGPT application as the dependent variable. We selected three green production technologies that are more commonly used in different production stages in Hunan. According to the number of AGPT adopted by farmers, we set the dependent variable as not adopted = 0, adopted 1 kind = 1, adopted 2 kinds = 2, adopted 3 kinds = 3.

Fig. 2 shows the number and type of AGPT adoption by farmers. As can be seen from Fig. 2(a), among the 613 rice farmers we surveyed, nearly 43.88 % of rice farmers adopted only one type of AGPT, 33.61 % of farmers adopted two types of AGPT, and only 48 rice farmers adopted three types of AGPT. Furthermore, according to Fig. 2(b), the adoption of GPCT was the highest at 71.29 %, SRT was the second highest at 46.33 %, and the adoption of STFT was the lowest at 16.97 %.This phenomenon may be related to farmers' unclear perception of the benefits of STFT.

3.1.2. Independent variables

Perceived value is a measurement of the perceived benefits and perceived costs of a service or product by an actor [45,46]. Improving farmers' perceived benefits and reducing perceived risk are effective ways to promote farmers' economic behavior. Among them, the perceived benefits of farmers' AGPT adoption can be manifested as increasing grain output and agricultural income, improving soil quality and farmland ecological environment; and the perceived risks can be manifested as the increase of machinery operating costs and factor input costs due to the adoption of AGPT, as well as a reduction in grain output due to irrational use of green technology [35,47]. Therefore, this paper measured farmers' perceived value from two dimensions: perceived benefits and perceived risks. Based on the previous analysis, we measured the perceived benefits and perceived risks of farmers by asking the respondents the following questions, as detailed in Table 1, the answers to the above questions were given on a 5-point Likert scale, from "highly disagree" to "highly agree" with values of 1, 2, 3, 4, and 5. Subsequently, we will measure farmers' perceiced benefit and perceiced risk by calculating their weighted average based on the values of the questions included in the farmers' value perception.

Policy subsidies refer to the financial compensation or incentives given by the government to farmers to encourage the adoption of AGPT. Therefore, we quantified it by asking farmers the special question (see Table 2). Furthermore, scholars found that market economic incentives based on the price mechanism can increase the price of green agricultural products to ensure farmers' returns [48]. Therefore, we measured market incentives by whether or not the adoption of AGPT can increase the market price of agricultural products.

3.1.3. Control variables

On the basis of theoretical analysis [25,35,49–51], we mainly introduced the three types of control variables: firstly, the characteristics of individual farmers and households, mainly including age, education level, annual household income, and work experience of village cadres. Secondly, the resource endowment of farmers, including planting scale, terrain, soil fertility, and authorization of farmland. The third is the agricultural production situation of the farmers, including whether they join cooperatives and whether they purchase agricultural socialization services. The definition and descriptive statistical analysis of each of the above variables are shown in Table 2.

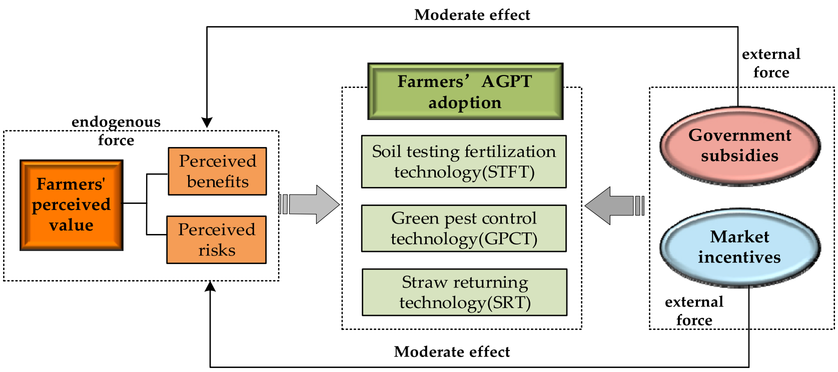

Fig. 1. Theoretical framework of farmers' AGPT adoption.

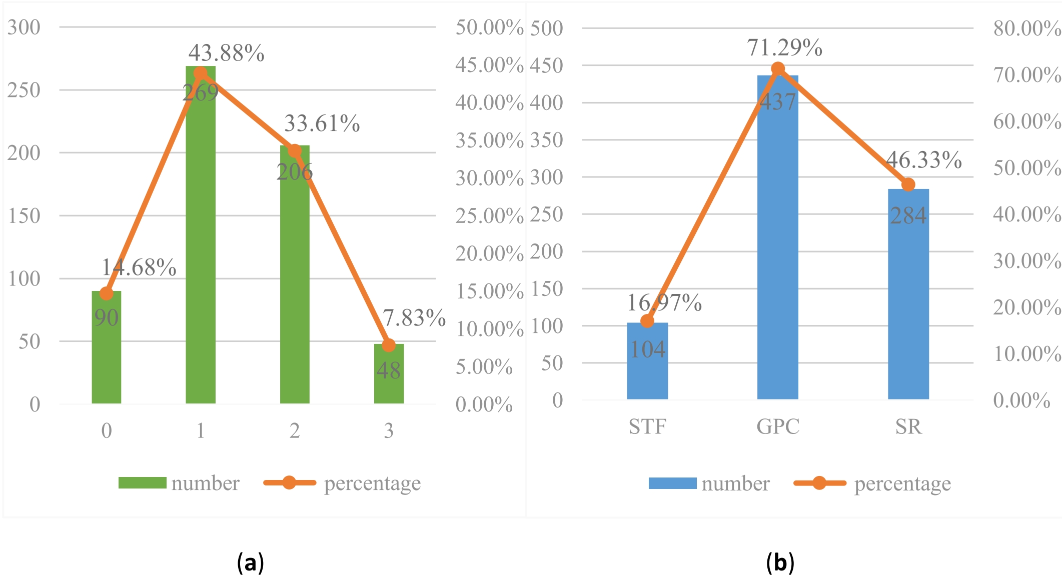

Fig. 2. The adoption of AGPT: (a) The quantity of AGPT adopted by farmers; (b) The adoption of different types of AGPT.

Table 1
Measurement of independent variables.

Independent variables	Indicators	Interview questions	Mean
Perceived benefits	Grain output increased	Do you agree that the adoption of AGPT can realize an increase in grain output?	2.945
	Agricultural income increased	Do you agree the adoption of AGPT can realize the increase of agriculture income?	2.648
	Eco-environment improved	Do you agree the adoption of AGPT can maintain soil fertility and improve the ecological environment of farmland?	3.661
Perceived risks	Production risk increased	Do you agree the adoption of AGPT will lead to a decrease in grain output?	3.033
	Production cost increased	Do you agree the adoption of AGPT will lead to an increase of agricultural production cost?	3.775

Table 2
Descriptive statistics of study variables (N = 613).

Control Variables	Definition	Mean	SD
Dependent variable			
AGPT	Number of green technologies adopted by farmers, including Soil test fertilization technology (STFT), Green pest control technology (GPCT), Straw returning technology (SRT)	1.346	0.823
Independent variables			
Benefit	Perceived Benefits	3.084	0.556
Risk	Perceived Risks	3.404	0.594
Market	“Do you agree the adoption of AGPT can increase the market price of agricultural products?”0-5	3.096	0.777
Policy	“Have you ever received economic subsidies from the government for the adoption of AGPT?” 1 = yes,0 = no	0.718	0.450
Control variables			
Age	Age of farmers	56.52	11.67
Edu	Education background; 1 = Elementary school degree and below; 2 = Junior high school degree; 3 = Senior high school degree; 4 = Junior College degree; 5 = Bachelor’s degree or above	1.985	0.827
Inc	Annual household income (unit: ten thousand yuan)	14.20	41.96
Cad	Whether your family menbers has ever served as a village cadre?1 = yes,0 = no	0.173	0.378
Land	The cultivated land area of operation (unit: mu)	36.93	224.8
Terrain	The terrain of the farmland; 1 = plain; 2 = hill; 3 = mountain	1.339	0.529
Soil	Soil fertility; 1 = very poor 2 = relatively poor 3 = average 4 = relatively fertile 5 = very fertile	3.248	0.696
Right	Whether your family’s land has obtained a land titling certificate? 1 = yes,0 = no	0.853	0.354
Coo	Whether to join a cooperative?1 = yes,0 = no	0.147	0.354
Service	Whether to purchase agricultural socialization services?1 = yes,0 = no	0.576	0.495

Table 2 demonstrates the descriptive statistics of variables in our research. The mean value of farmers' AGPT adoption is 1. 346, indicating that farmers have adopted at least one green technology. The mean values of farmers' perceived benefits and perceived risks are 3.084 and 3.404, respectively, indicating that the respondents' perceived benefits and perceived risks of AGPT are relatively high. In addition, the age range of the research participants lies between 21 and 83 years old, and their average age 56.52 years old, which is matched with the current situation of aging agricultural production in China; 77.65 % of the interviewees have junior high school education or below, indicating that the overall education level of farmers is on the low side. The average annual household income of farmer is $19,511.25, which shows that the income of rural households in China has increased, and according to the research practice, this is mainly due to the increase of wage income after the process of migrant workers' labor. In addition, the proportion of farm household members who are village cadres is 17.3 %. The average cultivated land operated by farm households is 2.463 ha. In addition, the mean values of terrain and soil fertility of operated arable land are 1.339 and 3.248, which indicated that the terrain of the study area is mainly plains and hills, and the soil fertility is relatively good. In addition, 85.3 % of rural households have obtained land ownership certificates; 14.7 % of the farmers are members of cooperatives, and 57.6 % of the farmers purchased agricultural socialized services in grain production.

3.2. Models setting

3.2.1. Multiple ordered regression model

Logistic regression model is mostly used to conduct empirical research where the dependent variable is qualitative data, mainly to verify the specific trend and degree of influence of the independent variable. So we verify the influence of farmers' perceived value on their AGPT adoption behavior by logistic model, and the basic expressions are shown in equation (2).

$$Y = \beta_0 + \beta_1 Benefit + \beta_2 Risk + \partial X_i + \varepsilon_i \tag{2}$$

Considering that the dependent variable is farmers' AGPT behavior, and its assignment is set to 0,1,2,3; which is the typical ordered multicategorical variables, so we use the multiple ordered regression model, and the basic expression is as follows.

$$ln\left[\frac{p(y \le n)}{1 - p(y \le n)}\right] = \propto_n + \sum_{m=1}^{k} \beta_m x_m \tag{3}$$

In equation (3), n denotes the number of AGPT adopted by farmers; y is the farmers' AGPT adoption; x_m denotes the variables affecting AGPT adoption; $\propto_n$ is the intercept term; β_m is the regression coefficient.

3.2.2. Probit model

For analyzing the effect of farmers' perceived value on the their AGPT adoption in different production stages, this paper uses whether to adopt soil testing and formulation technology (STFT), green pest control technology (GPCT), and straw return technology (SRT) as the dependent variable, and the perceived benefit and risk as the key independent variables, then using a probit model to estimate their impacts. The specific model is as follows.

$$Pro(y_i = 1|X_i) = \varnothing(\beta_0 + \beta_1 Benefit + \beta_2 Risk + \partial X_i + \varepsilon_i) \tag{4}$$

In equation (4), y_i represents whether farmers adopt STFT, GPCT, SRT or not, and $y_i = 1$ indicates that farmers adopted a certain agricultural green technologies. X_i represents the set of control variables affecting farmers' AGPT adoption, ε_i is random disturbance item, β is the coefficient estimation vector of the regression model, and $\varnothing$ denotes the probability function of normal distribution.

3.2.3. Moderating model

In order to further examine the moderate role of policy subsidies and market incentives between perceived value and farmers' AGPT adoption. Firstly, policy subsidies and market incentives are added into the model for regression respectively, and the specific formulas are shown in equation (5) and quation (6).

$$Y = \beta_0 + \beta_1 Benefit + \beta_2 Risk + \beta_3 Market + \partial X_i + \varepsilon_i \tag{5}$$

$$Y = \beta_0 + \beta_1 Benefit + \beta_2 Risk + \beta_3 Policy + \partial X_i + \varepsilon_i \tag{6}$$

Subsequently, the interaction terms of perceived value with policy subsidies and market incentives are added to the model, and the basic expressions are shown in equations (7) and (8).

$$Y = \beta_0 + \beta_1 Benefit + \beta_2 Risk + \beta_3 Market + \beta_4 Benefit * Market + \beta_5 Risk * Market + \partial X_i + \varepsilon_i \tag{7}$$

$$Y = \beta_0 + \beta_1 Benefit + \beta_2 Risk + \beta_3 Policy + \beta_4 Benefit * Policy + \beta_5 Risk * Policy + \partial X_i + \varepsilon_i \tag{8}$$

3.3. Study area and data collection

This paper chooses Hunan Province as the research area because it is one of China's main grain-producing provinces, with rice planting area and production at the forefront, and the province's grain sowing area of 4765.5 thousand hectares in 2022, producing

4.5 % of China's grain with 2.8 % of arable land, making a positive contribution to China's stable grain production and supply. However, Hunan Province is also facing great environmental pressure, and the abuse of chemical fertilizers and pesticides in agricultural production has led to serious pollution of its agricultural non-point sources. In December 2021, China's Central Ecological Environment Inspection team pointed out that Hunan Province's agricultural non-point source pollution control was ineffective, especially Changde, Yiyang and Yueyang cities. So Hunan provincial agricultural departments have to carry out corrective actions, strengthen the promotion and application of GPCT and STFT, and reduce agriculture pollution. Thus, the selection of our sample area is realistic and representative.

To ensure the scientific validity and completeness of the questionnaire, we conducts face-to-face interviews with 20 rice farmers in Yuepeng Village, Xitang Township, Yueyang City, including five village cadres who are very familiar with the local agricultural production situation, before we conducts the formal survey. Then we adjust the content of the questionnaire relied on the suggestions of the interviewees. The questionnaire consist of three parts: (1) basic information about the interviewees' individuals and families; (2) basic information about the farmland operated by the farmers; (3) the information about farmers' AGPT adoption and perception; (4) Policy support for AGPT.

Considering various factors such as economic level, the popularization of AGPT, and the feasibility of the survey in various cities in Hunan, we selects five cities, namely Hengyang, Yueyang, Changde, Yiyang, and Yongzhou, as the sample survey areas (see Fig. 3). Based on the size of the townships and populations of the counties and their geographic locations, we choose two townships from each county, and three villages are chosen from each township, and then adopted simple random sampling method to randomly invite 10–20 farmers in each village to conduct questionnaire survey The official survey is conducted from May to June in 2023. In addition, for ensuring the authenticity of the data, we communicate with village cadres where the research site is located in advance to understand the basic situation of their agricultural production. Afterwards, we go to the farmers' houses in the village, adopt face-to-face interviews, ask the farmers about the questions in the questionnaire, and record their answers to complete the data collection. A total of 650 questionnaires are sent out, and after deleting the questionnaires with no rice-planting and a lot of missing valid information, 613 valid questionnaires are finally obtained.

4. Results

4.1. Impact of farmers' perceived value on their AGPT adoption

To ensure the accuracy and effectiveness of the regression results, the variables are tested for multicollinearity, in which the values of the variance inflation factor (VIF) is 1.80, indicating that there is no serious collinearity problem between the independent variables. Then, we use the multiple ordered logistic regression model to analyze the influence of farmers' perceived value on their AGPT adoption, and the results are displayed on Table 3 and Fig. 4.

From the results in Table 3, perceived value significantly influences farmers' AGPT adoption through perceived benefits and

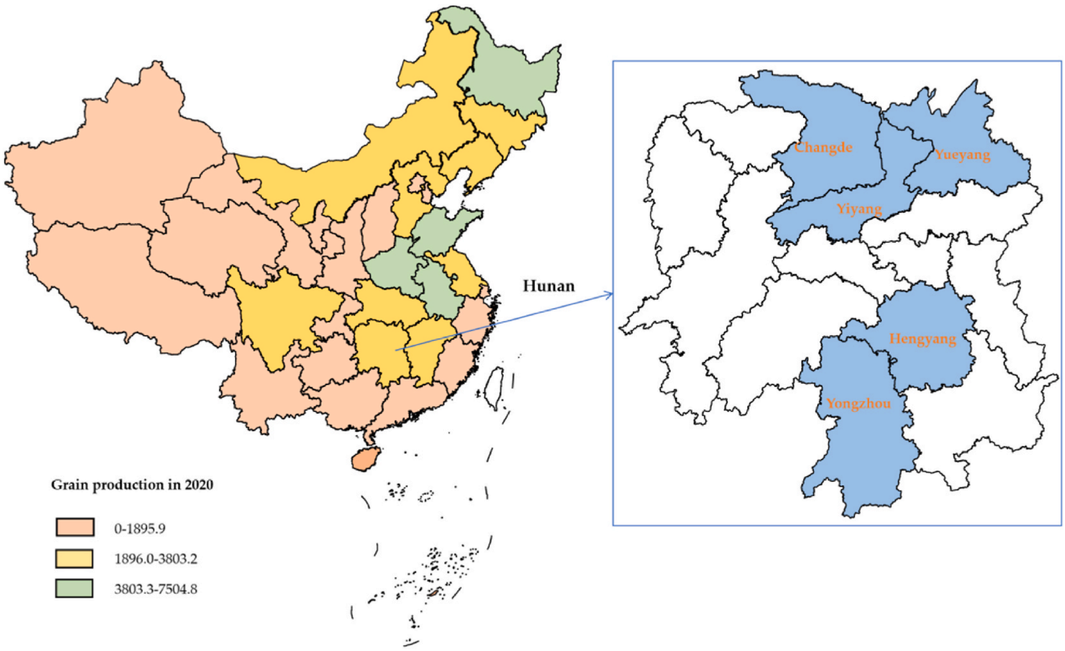

Fig. 3. Grain production (10,000 tons) and research survey areas in China in 2020. The Data source come from National Statistical Yearbook (http://www.stats.gov.cn/).

Table 3
Regression results of the perceived value on farmers' AGPT adoption.

Variables	AGPT		STFT		GPCT		SRT	
	Coef	Std. err	Coef	Std. err	Coef	Std. err	Coef	Std. err
Benefit	0.644***	0.162	0.371***	0.130	0.310***	0.117	0.125	0.107
Risk	−0.460***	0.153	−0.058	0.123	−0.388***	0.111	−0.170*	0.103
Age	−0.010	0.008	−0.010	0.007	0.001	0.006	−0.007	0.005
Edu	0.110	0.108	0.119	0.091	−0.103	0.077	0.127*	0.073
Inc	0.016***	0.005	0.011***	0.004	0.001	0.004	0.005	0.004
Cad	−0.268	0.212	−0.155	0.180	0.155	0.158	−0.334**	0.146
Land	−0.002**	0.001	−0.002**	0.001	0.001	0.001	0.000	0.001
Terrain	−0.167	0.164	−0.068	0.126	0.298**	0.118	−0.288***	0.107
Soil	0.621***	0.118	0.307***	0.097	0.210**	0.082	0.273***	0.078
Right	0.308	0.227	0.271	0.203	0.368**	0.159	−0.147	0.151
Coo	0.153	0.240	0.255	0.178	−0.131	0.178	0.035	0.163
Service	0.876***	0.170	0.391***	0.142	0.385***	0.159	0.316***	0.113
_cons	–	–	−3.172***	0.883	−0.335	0.747	−0.343	0.700
N	613		613		613		613	
Wald or LR value	115.630		67.630		69.460		59.730	
Log likelihood	−676.171		−245.311		−332.790		−393.381	
Pseudo R2	0.088		0.121		0.095		0.071	

Note: *, ** and *** indicate significant at the 10 %, 5 % and 1 % levels, respectively. And Coef is abbreviation of coefficient, SD is standard error.

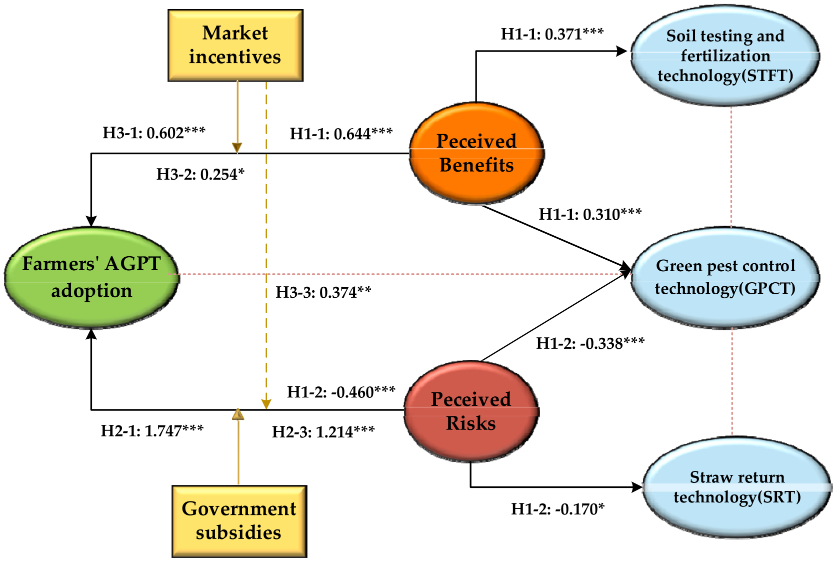

Fig. 4. The result of hypothesis test.

perceived risks. Among them, perceived benefits can promote farmers' AGPT adoption, indicating that farmers will consider the increased economic benefits expected to be brought by green technologies when making decisions, and different farmers will produce different value judgments due to the differences in cognitive level. When farmers' perceived benefits of adopting AGPT are stronger, they are more willing to engage in technology adoption. On the other hand, perceived risks has an inhibitory effect on farmers' AGPT adoption. This corroborates the findings of Li et al. (2022) [35]and Wang et al. (2022) [52]and confirms our hypotheses 1-1 and 1-2.

Specifically, as China continues to publicize and promote AGPT, farmers have begun to gradually understand the economic value of AGPT, and to consider the production risks that they should take when benefiting from green technologies. As rational economic beings, farmers always make production decisions that are conducive to maximizing their own profits on the basis of predicting the consequences of their economic behavior. We believe that farmers think that the adoption of AGPT can increase agricultural output, reduce farmland ecological pollution, contribute to the quality and safety of agricultural products and human health, and can bring corresponding market premiums for food products. Through the recognition of the perceived benefits of green technologies, farmers' AGPT adoption can be influenced.

Combined with the actual situation in China, those who stay in the countryside to plant crops are the older age people, who have relatively low education levels, high risk aversion; and their perception of the costs involved in adopting AGPT and the production risks that may result is stronger, which inhibits the adoption of AGPT to a certain extent. Therefore, it is foreseeable that increasing the perceived benefits of farmers' interests, especially increasing agriculture income, and decreasing the perceived risks, especially decreasing production costs, can help to promote the perceived value of AGPT.

The control variables of farmers' age, annual household income, terrain and geology of the operating arable land, and whether or not to purchase agricultural socialization services passed the significance test. Among them, the age of farmers can inhibit their AGPT adoption. Older farmers are more accustomed to traditional farming methods, difficult to accept the possible risks of new technologies, and unwilling to try green technologies. The higher household income means that farmers are more capable of undertaking the risks and cost brought by AGPT, so they are more inclined to adopt AGPT. In addition, the terrain and geology of farmers' cultivated land can facilitate farmers' AGPT adoption. This may be due to China's traditional farming culture, which makes Chinese farmers deeply attached to the land. Especially when the terrain of their farmland is flatter and the soil is more fertile, farmers are more willing adopt AGPT to obtain sustainable high grain output.

In addition, we found that the purchase of agricultural socialization services by farmers can significantly promote farmers' AGPT adoption. At present, China have provided economic subsidies for the agriculture socialized service organization to use green technologies. Furthermore, agricultural socialized service organizations have advanced agricultural machinery, technical personnel and other resource advantages, can reduce the cost of services and technology costs through the hosting of the agricultural production chain and continuous operation to promote farmers' AGPT adoption [53,54].

4.2. *Perceived value on farmers' AGPT adoption in different stages*

To further analyze the effect of farmers' perceived value on their AGPT adoption, We utilizes equation (4), respectively, with the adoption of soil formula fertilization technology (STFT), green pest control technology (GPCT), and straw return technology (SRT) as the dependent variable, and perceived benefits and perceived risks as the key independent variable, if technology is adopted, the value is 1, otherwise, the value is 0. The estimation results are included in Table 3 and Fig. 4.

(1) Soil testing and formulation technology (STFT) in the pre-production stage. Perceived benefits significantly and positively affected farmers' adoption of STFT. Farmers' production decision is the result of maximizing their own economic benefits. STFT is based on soil nutrients and fertilizer demand for crop growth, targeted fertilization on demand. Studies found that STFR can reduce the misuse of chemical fertilizers and also improve grain output and soil fertility [55–57]. This means that technology adoption can increase farm income and reduce costly inputs. Therefore, farmers' perceived benefits can promote their use of STFT.
(2) Green pest control technology (GPCT) in the mid-production stage. Both perceived benefits and perceived risks can affect the adoption of GPCT. GPCT can reduce the use of pesticides through biological control, physical pest removal and other ways to effectively decrease crop pests and diseases [58–60]. In addition, GPCT can also guarantee the safety of agricultural products, which is conducive to the certification of green and organic agricultural products, thus increasing the price of food products. On the other hand, the adoption of GPCT requires farmers to purchase additional high priced biopesticides and equipment such an insecticidal lamps, which leads to an increase in production inputs and time costs for farmers. Therefore, farmers' perception of benefits and risks can significantly inhibit the adoption of GPCT.
(3) Straw return technology (SRT) in the post-production. Perceived risks significantly and negatively influences farmers' adoption of SRT. After the crop harvest, the economic benefits that farmers can obtain in this round of crops have been basically determined, and how to deal with crop straw with low cost and high efficiency has become the biggest demand of farmers in the current process. SRT requires professional agricultural mechanization to crush the crop straw to fertilize the field. If the straw is returned directly to the field, additional nitrogen fertilizer is needed to accelerate the decomposition of the straw, which leads to an increase in the cost of SRT. In addition, crop straws contain a large number of bacteria and eggs, and improper treatment will

Table 4
The effect of policy subsidies and market incentives.

Variables	AGPT		AGPT	
	Coef	Std. err	Coef	Std. err
Policy	1.747***	0.198		
Market			0.602***	0.106
Age	−0.018**	0.008	−0.015*	0.008
Edu	0.205*	0.110	0.083	0.108
Inc	0.017***	0.005	0.020***	0.005
Cad	−0.251	0.215	−0.247	0.213
Land	−0.002**	0.001	−0.003***	0.001
Terrain	−0.120	0.164	−0.031	0.161
Soil	0.603***	0.120	0.613***	0.119
Right	0.162	0.231	0.300	0.226
Coo	0.058	0.240	0.181	0.240
Service	0.916***	0.169	0.737***	0.169
N	613		613	
Wald value	140.870		102.360	
Log likelihood	−653.880		−679.574	
Pseudo R2	0.118		0.083	

aggravate crop diseases and pests, resulting in reduced production of crops. Therefore, the perceived risks of farmers will significantly inhibit the adoption of SRT.

4.3. Impacts and mechanisms of policy subsidies and market incentives on green technologies adoption by farmers

The main purpose of policy subsidies and market incentives is to directly or indirectly realize the effective transmission of information and value through relevant measures, so as to promote farmers' AGPT adoption by strengthening their value cognition. According to the results in Table 4, both policy subsidies and market incentives are significant at the 1 % level, indicating that government economic subsidies and market price incentives can promote farmers' AGPT adoption. The possible reason is that the economic benefits such as subsidies and the expectation of agricultural product price increase can make farmers feel the benefit of technology application, and compensate for the cost of AGTP to a certain extent, thus promoting farmers' AGPT adoption [19].

Before conducting the regressions, we decentralize the core variables to reduce multicollinearity among the variables. Based on the results of Table 5, the interaction term of perceived risks with policy subsidies and market incentives passes the significance test. This indicates that market incentives play a significant moderate role in perceived risks and farmers' AGPT adoption behavior. The interaction term of perceived benefits and market incentives also passes the significance test. This indicates that the increase of farmers' expectation on the price of green agricultural products can improve farmers' perceived benefits and promote their technology adoption. Combined with the previous analysis, farmers' AGPT adoption is due to the cost-benefit trade-off. Through external government and market means, the social benefits generated by the adoption of AGPT can be transformed into private benefits, which is a fundamental measure to promote its adoption. In addition, the adoption of AGPT requires more time, learning and economic costs, while policy subsidies can make up for agriculture costs of farmers and effectively promote farmers' AGPT adoption [19].

At present, the low degree of adoption of AGPT in China is due to the imperfect development of China's agricultural market at this stage, the price mechanism has not fully played its role, green agricultural products are difficult to sell at high prices, especially green agriculture products. So farmers' gains from the adoption of green technologies can not even make up for their input. Although the government has taken measures such as subsidy incentives and technical training, there are a large number of small farmers in China, and this kind of universal subsidy is often difficult to make up for the cost of green technologies adoption by farmers, but instead increases the pressure on the government's finances [10].

According to Hunan Province's agricultural policy, the province's arable land fertility protection subsidy standard is 112 yuan per mu. Farmers enjoying the subsidy are required to raise awareness of the protection of agricultural ecological resources, proactively cultivate green fertilizers, promote the return of straw and animal manure to the land, increase the application of organic fertilizers, promote pest control and green prevention and control, and rotate cropping on arable land, among other measures, in order to enhance the quality of farmland. But in the process of agricultural production, per acre of arable land needs to be fertilized seeds, fertilizers, pesticides, machinery and other costs far exceeded the amount of subsidies, under the premise of China's low food prices, though policy subsidies to make up for the cost caused by adopting AGPT is far from enough.

But market incentive can directly affect the cost-benefit expectation in the form of agricultural income, and plays a more obvious role in changing farmers' perceived value and promoting the adoption of AGPT. Therefore, on the foundation of continuously optimizing government's economic subsidies, strengthening the coordination and complementation of the two forces of the government

Table 5
The moderate effects of policy subsidies and market incentives.

Variables	AGPT		AGPT		AGPT		AGPT	
	Coef	SD	Coef	SD	Coef	SD	Coef	SD
Benefit	0.344*	0.169	0.118	0.307	0.392*	0.177	−0.288	0.472
Risk	−0.444***	0.155	−1.316***	0.295	−0.467***	0.155	−1.619***	0.554
Policy	1.576***	0.204	−3.931**	1.786				
c_Benefit*c_Policy			0.429	0.366				
c_Risk*c_Policy			1.214***	0.343				
Market					0.441***	0.116	−1.639*	0.865
c_Benefit*c_Market							0.254*	0.149
c_Risk*c_Market							0.374**	0.168
Age	−0.013*	0.008	−0.014*	0.008	−0.010	0.008	−0.010	0.008
Edu	0.179	0.110	0.185*	0.110	0.076	0.109	0.069	0.109
Inc	0.014***	0.005	0.013**	0.005	0.016***	0.005	0.016***	0.005
Cad	−0.231	0.216	−0.272	0.217	−0.234	0.213	−0.236	0.213
Land	−0.001*	0.001	−0.001	0.001	−0.002**	0.001	−0.002**	0.001
Terrain	−0.262	0.168	−0.215	0.170	−0.175	0.165	−0.201	0.167
Soil	0.611***	0.120	0.622***	0.120	0.619***	0.119	0.637***	0.119
Right	0.168	0.233	0.227	0.235	0.284	0.228	0.268	0.227
Coo	0.057	0.241	−0.015	0.243	0.181	0.242	0.187	0.247
Service	0.987***	0.172	0.983***	0.174	0.837***	0.171	0.855***	0.172
N	613		613		613		613	
LR value	158.660		115.940		206.680		150.450	
Log likelihood	−644.197		−668.875		−637.800		−665.911	
Pseudo R2	0.131		0.098		0.139		0.102	

and the market, and utilizing the price mechanism of the agricultural market to promote the adoption of AGPT seems to be very crucial. Government departments should focus on creating green agricultural products characteristic brand, strengthen the certification of green and organic agricultural products, improve the agricultural market regulatory system, solve the problem of asymmetric information in the agricultural market, realize the green agricultural products of high quality and good price, so as to enhance the farmers' perception of the benefits of the green technologies, and to promote the adoption of AGPT.

4.4. Robustness test

The robustness test is conducted by replacing the explanatory variables and changing the method of analysis. By replacing the explanatory variable with "whether to adopt agricultural green production technology", we re-run the regression using the probit model (see Modle1,2,3). Furthermore, we replace the explanatory variable "whether to receive policy subsidies" with "the amount of government subsidies" and re-run the regression using an ordered regression model (see Modle4). The regression results are shown in Table 6, and we found that the degree and direction of significance of the core explanatory variables have not changed significantly, which means the results of this paper are more reliable.

5. Conclusions

Agricultural pollution has become an important constraint to agriculture sustainable development in China, and the green transformation of traditional high-pollution agriculture is imminent. Reasonably guiding farmers' perceived value of green technologies and promoting their adoption is the key to realizing sustainable agricultural development. Correctly inducing farmers to adopt green technologies is the key to promoting sustainable agricultural development. Through the household survey data of 613 rice farmers in Hunan, we use a multiple ordered regression model and a probit model to explore the influence of farmers' perceived value on their AGPT adoption, and test the moderate role of policy subsidies and market incentives. The following research conclusions were drawn:

Firstly, perceived value can obviously affect farmers' AGPT adoption. Farmers' AGPT adoption is a trade-off between perceived benefits and perceived risks, and farmers' perceived benefits can significantly facilitate their AGPT adoption, while perceived risks inhibited the technologies adotption. Second, farmers' adoption of AGPT in different production stages are influenced by different perceived values. The adoption of STFT in the pre-production stage is significantly affected by the perceived benefits; the adoption of GPCT in the mid-production stage is significantly affected by both the perceived benefits and the perceived risks; and the adoption of SRT in the post-production stage is significantly affected by the perceived risks.

Therefore, in order to increase farmers' awareness of green production technologies, government departments should aggressively promote and provide training on green production technologies, including soil testing and fertilization technologies, green pest control technologies. Agricultural departments should also conduct test the soil composition of farmland, monitor crop pests and diseases in real time, promptly notify farmers of the results of soil tests and pest and disease forecasts, so as to require them to use chemical fertilizers and pesticides in accordance with the actual situation. In addition, government departments should collaborate with market departments to strengthen the quality certification of agricultural products, and realize the growth of agricultural prices and farmers' income through pollution-free agricultural certification, green food certification and organic food certification, so as to improve the farmers' perceived benefits of green technology, and thus enhance the farmers' enthusiasm for adopting AGPT. Besides, in order to lower the costs of green pest control technology for farmers, the government can also offer free equipment like insecticidal lamps, give tax concessions to agricultural businesses that produce low-toxicity and pollution-free pesticides and biopesticides. The government can also include combine harvesters with the function of straw crushing in the scope of subsidies for the purchase of agricultural machinery and increase the subsidies, thus reducing the labor cost of straw return to the field and promoting the use of AGPT. Agricultural technicians should also actively participate in agricultural production experiments, provide farmers with detailed and professional guidance, inform farmers of the key points and precautions of each green technology, reduce the risk of grain output reduction due to the irrational use of AGPT, and improve farmers' perceived value of AGPT.

Secondly, policy subsidies can promote farmers' AGPT adoption, and have a positive moderating effect between risk perception and farmers' AGPT adoption. Market incentives can play a substitute role for policy subsidies, and can also increase the perceived benefits and perceived risk of green technologies, and promote the adoption of green technologies by farmers. Therefore, we must thus fully utilize the complementary functions of policy subsidies and market incentives for the adoption of AGPT. On the one hand, the government should gradually increase the subsidies for green technologies, and but also provide farmers with pest-resistant seeds, organic fertilizers and other ways to reduce farmers' cost of adopting AGPT. On the other hand, governments should play the role of market regulation, guide the improvement of the market price mechanism of agricultural products, strengthen the quality certification of agricultural products, and support agricultural enterprises to establish the traceability system of agricultural products by financial subsidies or tax incentives, then reducing the information asymmetry of agricultural products market. Then making agricultural products produced by farmers who adopt agricultural green production technology can be sold at a high price, thus improving the enthusiasm of farmers to adopt green technologies.

Our research contributes to a deeper understanding of farmers' green technology adoption, but there are still some limitations worth considering: firstly, we explored the impact of policy subsidies on the adoption of farmers' AGPT, and more valuable conclusions might have been drawn if we had access to the specific amount of subsidies for green production. Besides, due to the small sample area, it is difficult to draw universal opinions and recommendations, so policy makers should consider regional differences in terrain and geology and farming practices when designing policies to encourage farmers to adopt green technologies.

Table 6
Robustness test results.

Variables	Model1		Model2		Model3		Model4	
	Coef	Std. err	Coef	Std. err	Coef	Std. err	Coef	Std. err
Benefit	0.399**	0.143						
Risk	−0.577***	0.137						
Policy			1.247***	0.147			0.016***	0.002
Market					0.361***	0.092		
Age	−0.006	0.007	−0.016**	0.007	−0.01	0.007	−0.017**	0.008
Edu	−0.027	0.092	0.029	0.093	0.076	0.090	0.192*	0.109
Inc	0.01	0.006	0.01	0.007	0.016***	0.007	0.017***	0.005
Cad	−0.035	0.185	0.006	0.192	−0.234	0.181	−0.209	0.215
Land	−0.001	0.001	−0.001	0.002	−0.002**	0.002	−0.002**	0.001
Terrain	0.06	0.141	0.119	0.139	−0.175	0.138	0.015	0.163
Soil	0.218**	0.096	0.196*	0.101	0.619***	0.095	0.553***	0.120
Right	0.178	0.188	0.037	0.195	0.284	0.185	0.137	0.231
Coo	−0.036	0.220	−0.308	0.230	0.181	0.218	0.044	0.241
Service	0.665***	0.143	0.620***	0.147	0.837***	0.139	0.967***	0.170
N	613		613		613		613	
Wald value	44.65		97.13		36.65		132.34	
Log likelihood	−218.037		−198.652		−228.64		−654.625	
Pseudo R2	0.147		0.223		0.106		0.117	

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Data availability statement

Data will be made available on request.

Institutional review board statement

After consideration by Institutional Review Board, the research protocol of the study is scientifically sound, fair and impartial, does not cause harm or risk to the participants, the participants follow the principles of voluntary and informed consent and protection of the participants' rights, interests and privacy, and the research content is free from conflict of interest as well as violation of moral and ethical principles and legal prohibitions.

CRediT authorship contribution statement

Muziyun Liu: Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Hui Liu:** Writing – review & editing, Supervision, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

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