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Risk aversion, cooperative membership and the adoption of green control techniques: Evidence from China

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ABSTRACT

Green control techniques are helpful for ensuring the safety of the ecological environment. Their application offers important support for clean production among farmers, but their application level is not high because farmers are risk averse. To solve this dilemma, farmers' degree of risk aversion was measured through an experimental economics approach applied to the results of a survey of 385 vegetable farmers in Shandong Province. This study adopts an endogenous switching probit model to reveal the impact of vegetable farmers' risk aversion and cooperative membership on their adoption of green control techniques. Furthermore, it examines whether cooperative membership helps alleviate the inhibitory effect of risk aversion on the adoption of green control techniques among vegetable farmers. The results show that vegetable farmers' degree of risk aversion has a significant and positive impact on their cooperative membership and a significant and negative impact on their adoption of green control techniques, while their participation in cooperatives may not only promote their adoption of green control techniques but also alleviate the inhibitory effect of risk aversion on such adoption. To promote cleaner production by farmers, policymakers should reduce the risk of adopting green control techniques for farmers, increase support for cooperatives and improve the internal conditions and external environment to promote the adoption of green control techniques among farmers.

1. Introduction

Chinese farmers arbitrarily increase the dosage and frequency of chemical pesticide use and shorten the interval between uses (Ying and Xu., 2017), and such irregular behaviors have increased the average amount of chemical pesticides applied per unit area in China to 2.5–5 times the level in developed countries (Jin et al., 2017). Chemical pesticides have been transformed from being “tools for increasing crop production” to one of the “chief culprits” affecting the quality and safety of agricultural products, the safety of the ecological environment, and the safety of agricultural production. For this reason, the Chinese government has vigorously promoted green control techniques (GCT) by means of intensive publicity, technical training and quota subsidies. As the localized version of integrated pest management (IPM) in China, GCT is characterized by the prioritization of resource-saving and environmentally friendly technical measures, such as ecological regulation, biological and physical control and the scientific use of chemical pesticides. By the end of 2017, the rate of GCT coverage for major crops in China had reached 27.2%, but there is still a long way to go before achieving the goal of an over 50% coverage rate of major crops by 2022 (Yin et al., 2018). Many factors influencing GCT change slowly, such as gender, level of education, distance to the agricultural technology extension agent (Gao et al., 2019a), farm size, the share of non-agricultural income (Erbaugh et al., 2010), land tenure, and social capital (Gao et al., 2019b). In addition, farmers' risk aversion is also a key factor that influences their GCT adoption behavior (Gao et al., 2017a).

Although gender (Kolleh, 2016), age (Abebaw and Haile, 2013), level of education, geographical location (Abate et al., 2013), farm size, social capital (Mojo et al., 2017) and other factors influence whether farmers participate in cooperatives, in theory, encouraging

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farmer participation could effectively alleviate the inhibitory effect of farmers' risk aversion on GCT adoption behavior. First, cooperatives effectively reduce farmers' risk, and the higher the farmers' degree of risk aversion is, the more likely they are to participate in cooperatives (Duguma, 2016). Second, cooperatives not only provide farmers with information consultation services, production material procurement services, credit guarantee services, technical guidance services, unified acquisition services and other services but also organize technical cooperation and communication among farmers, which help farmers reduce production constraints, liquidity constraints, credit constraints, technology input costs and technology transaction costs, thereby promoting their adoption of technology. Cooperatives are an important channel for encouraging risk-averse farmers to adopt GCT. However, no empirical analysis has been conducted on whether farmers' membership in cooperatives helps to alleviate the inhibitory effect of risk aversion on GCT adoption.

It is also necessary to measure the degree of farmers' risk aversion to empirically study whether cooperative membership helps alleviate the inhibitory effect of risk aversion on GCT adoption behavior among farmers. At present, most existing studies use the following three methods to measure farmers' degree of risk aversion. The first is the scale measurement method, which is based on psychological principles and conducted through questionnaires (Howley et al., 2016). However, it is subjective and lacks real economic incentives; therefore, this approach may not be able to truly reflect farmers' degree of risk aversion (Iyer et al., 2018). The second is the experimental economics approach based on expected utility theory. The primary methods in this approach are the scenario experiment method designed by Eckel and Grossman (2002) and the multiple price list method proposed by Holt and Laury (2002). Both methods link farmers' level of risk aversion with a utility function and estimate the risk aversion coefficient in the utility function through experimental results obtained from the farmers to objectively reflect their degree of risk aversion. However, Eckel and Grossman's (2002) scenario experiment method cannot measure the risk aversion coefficient of risk-loving farmers (Charness et al., 2013). Subsequent studies have found that the scenario experiment method can be improved to measure the risk aversion coefficient of risk-loving farmers. For example, Reynaud and Counture (2012) has modified both the payoffs proposed originally Eckel and Grossman (2002) and the number of gambles the subjects had to choose among; Hermann and Muyhoff (2019) adapted to the general design of Eckel and Grossman (2002), but they have not been widely used in other studies. The third is the experimental economics approach, which is based on expected utility and cumulative prospect theory (Ward and Singh, 2015). This method expands the basic form of the farmer's utility function. In addition to a risk aversion coefficient, the utility function also includes a loss aversion coefficient and a nonlinear probability weighting to better reflect the farmers' risk preferences. However, Charness et al. (2013) noted that this method makes the utility function more complicated and the experimental process more difficult for farmers to understand, which makes it prone to measurement error. In summary, the multiple price list method combining experimental economics and psychology with real-world scenario testing and monetary rewards for participating farmers improves the ability to obtain real information on farmers' risk attitudes and has higher external validity (Anderson and Mellor, 2009), and the experimental process is simple and easy to understand more widely (Jin et al., 2019). Therefore, this paper uses the multiple price list method to measure farmers' degree of risk aversion.

The main contributions of this paper are as follows. First, using the experimental economics approach, this study measures Chinese vegetable farmers' degree of risk aversion, thereby enriching research on Chinese farmers' risk preferences. Second, this study determines whether being a member of a cooperative can alleviate the inhibitory effect of vegetable farmers' risk aversion on their GCT adoption behavior; thus, this study provides a new perspective on solving the difficulties of expanding the use of GCT that result from vegetable farmers' risk aversion.

2. Theory and hypothesis

In addition to maximizing profits, farmers also pursue risk minimization in their production decisions (Arief and Fitriani, 2018). Risk-averse farmers are usually cautious in their production decisions. Although their decisions may feature some unreasonable aspects, they essentially stem from a rational consideration for "avoiding disasters" (Ahsanuzzaman et al., 2015). GCT (IPM) reduces the use of chemical pesticides, increases production, and ensures safe agricultural production, safe agricultural product quality and environmental protection (Allahyari et al., 2016). Nonetheless, there are also certain risks in adopting GCT (IPM). The first risk is uncertainty in net profits. Due to the frequent price fluctuations of agricultural products in China, farmers are often at an informational disadvantage in terms of the market price, so their investment in adopting GCT may not yield the expected net profit. Moreover, as there is not yet a perfect market for green agricultural products in China (Zou et al., 2019), the existence of the "lemon effect" may mean that the high-quality agricultural products produced by farmers adopting GCT fail to achieve "high quality and high price" in the market, thus leading to uncertainty about net profits (Gao et al., 2017b). The second risk is the improper use of technology. GCT is a knowledge-intensive technology and has high requirements for technology adopters (Yaguana et al., 2016), which may expose farmers to a risk of improperly using GCT. Thus, this paper's first hypothesis is as follows.

H1. Risk aversion has a negative impact on farmers' GCT adoption behavior.

However, farmers' participation in cooperatives can effectively reduce the natural risk, the production risk and the market risk (Liu and Deng, 2012) they face. Farmers with higher risk aversion are more likely to participate in cooperatives to avoid risk. Therefore, this paper's second hypothesis is as follows.

H2. Risk aversion has a positive impact on farmers' participation in cooperatives.

Meanwhile, cooperatives can also promote farmers' technology adoption in the following ways. First, technology input costs and technology transaction costs can be apportioned across the entire cooperative, thereby significantly reducing the technology adoption costs of each individual farmer. Second, cooperatives provide farmers with production materials, procurement services and credit guarantee services, which help reduce their production, liquidity and credit constraints in technology adoption (Mao et al., 2014). Third, cooperatives provide common acquisition services for farmers, which can transfer some of the risk that farmers face from uncertain net profits to the cooperative. Fourth, cooperatives provide technical guidance for farmers and organize technical cooperation and communication among farmers, which reduces the risk of improper technology use. Thus, this paper's third hypothesis is as follows.

H3. Participation in cooperatives has a positive impact on farmers' GCT adoption behavior.

Based on the above theoretical analysis, the more risk-averse farmers are, the less likely they will be to adopt GCT. However, cooperative membership can reduce the inhibitory effect of farmers' risk aversion on GCT adoption behavior; that is, highly risk-averse farmers are more likely to participate in cooperatives. Therefore, the hypothesis presented in this paper is as follows:

H4. Farmers' membership in cooperatives can alleviate the inhibitory effect of risk aversion on GCT adoption behavior.

3. Method

This paper measures farmers' degree of risk aversion through an experimental economics approach and then uses the endogenous switching probit model to verify the hypothesis.

3.1. Experimental economics approach

The multiple price list method is an experimental economic method based on expected utility theory. Expected utility theory holds that farmers' risk aversion coefficient is the only parameter that determines the curvature of their utility function, and the lower the risk aversion coefficient, the greater the curvature of the utility function, and the more inclined the farmers are to take risks (Holt and Laury, 2002). This paper refers to the research of Holt and Laury (2002) and expresses the farmers' utility function as follows:

$$U(x) = \frac{x^{1-r}}{1-r} \tag{1}$$

where U is the utility function, x is the amount of the bonus that the farmer may receive in the experiment, and r is the risk aversion coefficient of the farmer; the greater r is, the less risk the farmer tends to take.

To measure farmers' risk aversion, this paper adjusts the bonus amount by a factor of 15 based on the multiple price list approach designed by Holt and Laury (2002), as shown in Table 1. After adjusting the bonus amount by a factor of 15, the bonus amounts considered in the experiment were 30 yuan, 24 yuan, 57.75 yuan and 1.5 yuan, which is similar to the income the farmers earn in half of a day. Thus, the bonus can compensate for the income lost by farmers while participating in the experiment and encourage them to participate. There are 10 multiple-choice questions in the table, with two options, A and B, in each group. Option A contains two different bonus amounts, the size of which remains unchanged: 30 yuan and 24 yuan. With the increase in the number, the probability of obtaining the larger bonus amount increases by 10%, and the probability of obtaining the smaller bonus amount decreases by 10%. Option B also contains two different bonus amounts, which remain unchanged at 57.75 yuan and 1.5 yuan, and the change in the probabilities of receiving the two bonus amounts is the same as for Option A. The range of the two bonus amounts in Option B is large and includes both the maximum bonus amount and the minimum bonus amount, and therefore Option B can be characterized by the phrase "the higher the risk, the higher the profit" and is called the "risky option". The sizes of the two-bonus amount in Option A are relatively similar, the bonus amount is much larger than the minimum bonus amount and slightly smaller than the maximum bonus amount, and thus Option A is called the "safe option". Initially, the probability of obtaining the maximum bonus amount in the "risky option" is low and the probability of obtaining the minimum bonus amount is high, the farmer will choose the "safe option". However, as the probability of obtaining the maximum bonus amount in the "risky option" increases and the probability of obtaining the minimum bonus amount decreases, this option becomes more attractive to farmers, and they will at some point switch from Option A to Option B. The investigator can identify a range of values for each farmer's risk aversion coefficient based on this inflection point. For example, if the farmer shifts from A to B in the fifth multiple-choice question, indicating that the he or she has selected Option A four times before, the lower limit and upper limit of the risk aversion coefficient for that farmer are:$0.3\frac{30^{1-r}}{1-r}+0.7\frac{24^{1-r}}{1-r}=0.3\frac{57.75^{1-r}}{1-r}+0.7\frac{1^{1-r}}{1-r}\Leftrightarrow r=-0.49$ and $0.4\frac{30^{1-r}}{1-r}+0.6\frac{24^{1-r}}{1-r}=0.4\frac{57.75^{1-r}}{1-r}+0.6\frac{1^{1-r}}{1-r}\Leftrightarrow r=-0.14$. Furthermore, the value range of the farmer's risk aversion coefficient is $-0.49<r<-0.14$. Following Vollmer et al. (2017), the midpoint of this interval is taken as the estimate of the risk aversion of farmers.

Table 1
The multiple price list.

Number	Option A		Option B	
1	30 (10%)	24 (90%)	57.75 (10%)	1.5 (90%)
2	30 (20%)	24 (80%)	57.75 (20%)	1.5 (80%)
3	30 (30%)	24 (70%)	57.75 (30%)	1.5 (70%)
4	30 (40%)	24 (60%)	57.75 (40%)	1.5 (60%)
5	30 (50%)	24 (50%)	57.75 (50%)	1.5 (50%)
6	30 (60%)	24 (40%)	57.75 (60%)	1.5 (40%)
7	30 (70%)	24 (30%)	57.75 (70%)	1.5 (30%)
8	30 (80%)	24 (20%)	57.75 (80%)	1.5 (20%)
9	30 (90%)	24 (10%)	57.75 (90%)	1.5 (10%)
10	30 (100%)	24 (0%)	57.75 (100%)	1.5 (0%)

Note: The number in parentheses is the probability of obtaining that bonus amount.

In addition, in a multi-price list, farmers may face multiple inflection points in the process of sequential selection. Multiple inflection points mean that farmers lack the understanding of multi-price lists and show that the behavior is not consistent and the experimental results are biased (Harrison et al., 2015). Therefore, this paper decided to follow the protocol of Tanaka et al. (2010) and requires farmers to make only one choice in the multi-price list before the experiment, and the selection number is then recorded to ensure that each farmer has a unique inflection point. To avoid the farmers' feeling that they are forced to make only one choice, also refers to the practice of Tanaka et al. (2010). Before starting the experiment, three examples are given for the farmers' reference. In one example, a subject switches in the sixth question; in one example, the subject chooses Option A for all questions, and in one example, the subject chooses Option B for all questions. However, using this approach, this paper is not able to identify participants who reveal multiple inflection points. For a discussion of this approach see Sanou et al. (2018). After completing the recording, the farmers are allowed to randomly select one group from 10 groups of questions; the actual experiments are conducted, and the farmers are rewarded with real money to ensure that all of their answers are rational.

3.2. Endogenous switching probit model

Unobserved factors may affect the determinants of farmers' cooperative membership and GCT adoption behavior. It is necessary to address the endogeneity problem when empirically analyzing whether farmers' cooperative membership can alleviate the inhibitory effect of risk aversion on GCT adoption behavior. To address endogeneity problems, most studies adopt the instrumental variable (IV) approach (Duguma, 2016). However, this approach is ineffective when the endogenous variable is a restricted binary variable (Wooldridge, 2014). To address this issue, Maddala (1983) proposed the recursive bivariate probit model (RBPM) and Miranda and Rabe-Hesketh (2006) proposed the endogenous switching probit model (ESPM), which have similar structures. Both methods use full information maximum likelihood, which effectively eliminates the endogeneity problem and yields unbiased estimates (Thuo et al., 2014). Unlike the RBPM, not only does the ESPM rely on the shared random effect to simulate the specific dependence of the error term between the switching equation and the outcome equation but also the standard error of the result estimated with the latter is smaller and closer to the real value (Hao et al., 2018). Therefore, this paper adopts the endogenous switching probit model (ESPM). This model contains the switching equation and the outcome equation. The switching equation is used to analyze the determinants of farmers' cooperative membership, while the outcome equation is used to analyze the factors impacting farmers' GCT adoption behavior. The specific form is as follows:

$$\begin{cases} C_i^* = a + \gamma_1 R_i + \beta_1 X_i + u_i \;\; C_i = 1 \; if \; C_i^* > 0, \; C_i = \; 0 \; otherwise \;\; < 1 > \\ T_i^* = b + \gamma_2 R_i + \theta C_i^* + \beta_2 Y_i + v_i \;\; T_i = 1 \; if \; T_i^* > 0, \; T_i = \; 0 \; otherwise \;\; < 2 > \end{cases} \tag{2}$$

In the formula, C_i^* indicates the observed value of cooperative membership for farmer i, which is the estimated coefficient in the outcome equation. $C = 1$ indicates that the farmer participates in cooperatives, and $C = 0$ indicates that the farmer does not participate in cooperatives. For the GCT adoption behavior of farmer i, $T = 1$ indicates that the farmer has adopted GCT, and $T = 0$ indicates that the farmer has not adopted GCT. R_i is farmer i's degree of risk aversion, where γ_1 and γ_2 define the estimated coefficients in the switching equation and the outcome equation, respectively. X_i and Y_i are control variables that affect the determinants of farmers' cooperative membership and GCT adoption behavior, respectively, where β_1 and β_2 indicate the respective estimated coefficients. a and b define the constant terms in the switching equation and the outcome equation, respectively. In addition, u_i and v_i define the random error terms in the switching equation and the outcome equation, respectively.

To further explore whether farmers' cooperative membership helps alleviate the inhibitory effect of their risk aversion on GCT adoption, based on the simultaneous switching and outcome equations in the ESPM, <1> in (2) is brought into <2>, and the following simplified equation is obtained:

$$T^* = m + (\gamma_2 + \gamma_1 \theta) R + \beta_3 Y + \beta_4 Q + \omega \tag{3}$$

where Y and Q are defined as the control variable and identification variable, respectively, and their respective coefficients are β_3 and β_4. Moreover, m is a constant, and ω is a random error term. γ_2 is the direct impact (theoretically negative and inhibitory) and $\gamma_1\theta$ is the indirect impact (theoretically positive and promoting) of the level of risk aversion on farmers' GCT adoption behavior, and thus $(\gamma_2 + \gamma_1\theta)$ is the total impact. If $(\gamma_2 + \gamma_1\theta) > 0$, the direct impact of farmers' degree of risk aversion on their GCT adoption behavior is less than the indirect impact, whereas if $(\gamma_2 + \gamma_1\theta) < 0$, the direct impact is greater.

4. Variables, data and descriptive statistics

This section introduces the selected variables and their basis, data sources, and descriptive statistical results.

4.1. Variable selection

This section introduces the selected variables and their theoretical justification, specifically:

4.1.1. Farmer GCT adoption behavior

T represents a farmer's adoption of GCTs. If the farmer adopts GCTs, then T equals 1 and 0 otherwise.

4.1.2. Farmer participation in cooperatives

C represents a farmer's participation in cooperatives. If the farmer participates in cooperatives, then C equals 1 and 0 otherwise.

4.1.3. Identification variable

To ensure the identifiability of the switching equation and the outcome equation, at least one control variable in the switching equation must be excluded from the outcome equation (Hao et al., 2018). Based on Mojo et al. (2017), this paper selects the distance to the nearest cooperative as the identification variable and tests its effectiveness. The test results showed that the identification variables were effective and had a significant and positive impact on cooperative membership but did not significantly influence farmers' GCT adoption. The distance to the nearest cooperative is measured as "actual distance to the nearest cooperative".

4.1.4. Control variables

Based on theories on farmer behavior and planned behavior and the main conclusions of the related literature, the control variables selected in this paper are as follows: 1) Age. Older householders not only tend to have more traditional concepts but also find it more difficult to absorb new technologies and knowledge, so they lack the enthusiasm to participate in cooperatives (Hill et al., 2008) and tend to be conservative about adopting new technologies (Brown et al., 2019). 2) Gender. Women tend to be more cautious, so they are more passive about adopting new technologies (Theis et al., 2018) and have a lower willingness to participate in cooperatives (Wang et al., 2009). 3) Degree of education. The more educated farmers are, the more advanced their concepts and horizons are, the more comprehensive their understanding of new technologies and cooperatives is, and the more likely they are to adopt new technologies (Gonzaga et al., 2019) and participate in cooperatives (Abate et al., 2013). 4) Farm size. The larger the farm is, the more motivated farmers are, given the scale effect, to adopt new technologies (Hu et al., 2019) and participate in cooperatives (Cai and Han, 2012). 5) Share of non-agricultural income. The higher farmers' share of non-agricultural income is, the less they depend on the income from agricultural production and operation, and the less likely they are to adopt new technologies (Erbaugh et al., 2010) and participate in cooperatives (Kolleh, 2016). 6) Number of laborers. The larger the number of laborers is, the less motivated the farmers are to invest capital in the introduction of new technologies (Gao et al., 2019a), and to participate in cooperatives (sun et al., 2013). 7) Frequency of communication with neighbors. The more frequently farmers communicate with their neighbors, the better they understand the advantages of new technologies and cooperatives, and the more motivated they are to adopt new technologies (Nakano et al., 2018) and participate in cooperatives (Yin et al., 2017). 8) Participation in training. Farmers' participation in training helps to improve their cognition of new technologies and thus their confidence (Rajput et al., 2014). Meanwhile, farmers who participate in training can obtain more information about co-operatives and are more likely to participate in cooperatives (Nugusse et al., 2013). 9) Social capital. Social capital can help alleviate the information asymmetry problem faced by farmers in the process of cooperative participation and new technology adoption to enable them to participate in cooperatives (Mojo et al., 2017) and adopt new technologies (Wuepper and Sauer, 2016). This paper refers to the research of Gao et al. (2019b) and considers three aspects of social capital—networks, norms and trust—and then uses a weighting method that combines the factor analysis and entropy methods to obtain indices of social capital. This paper measures networks based on farmers' report of "the total amount of money spent annually on relatives, neighbors and friends", measures norms by asking householders what the social atmosphere is like in their villages, and measures trust by asking householders whether they have lent money to relatives, neighbors, or friends. The network variable is measured with an actual numerical value, the norm variable is measured using a 7-point Likert scale, and the trust variables are coded as 1 for "yes" and 0 for "no".10) Land tenure. Land tenure security helps farmers ensure returns on investment and focus on the sustainability of agricultural production, which promotes the adoption of GCTs. However, land tenure security also lowers the farmers' need to take risks and makes it less likely that they seek help from external organizations such as co-operatives (Nugusse et al., 2013). In addition to social capital, measures of the above control variables are shown in Table 2.

4.2. Data sources

This paper analyzes Shandong Province for the following. First, as of 2016, the area under vegetable cultivation and the total output of Shandong Province has ranked first in the country for 10 consecutive years. Second, pest and disease epidemics are common in Shandong Province, and pest control is a serious problem (Gao et al., 2018). Third, the number of cooperatives in Shandong Province exceeds 100,000, and they have a good level of development.

The survey is divided into two stages: pre-investigation and formal investigation. In June 2017, 25 farmers were randomly selected for interviews in Weifang City, and a pre-investigation was conducted to capture the degree of risk aversion and GCT adoption. Based on the results of the pre-investigation, deficiencies in the questionnaire were addressed. This was followed by a formal investigation from July to September 2017. The core purpose of this study is to address the slow diffusion of GCT caused by farmers' risk aversion. Because the development level of cooperatives varies greatly among counties (cities and districts) in Shandong Province, 10 counties (cities and districts) with a large number of relatively concentrated cooperatives were first selected to obtain an effective sample of farmers participating in cooperatives (They are Shouguang City, Yanggu County, Tengzhou City, Wucheng County, Xin County, Sishui County, Yuan County, Yiyuan County, Gaoqing County, and Dongping County). Furthermore, all townships (towns) in the 10 counties (cities and districts) were sorted according to per capita income and divided into five levels: high, relatively high, medium, relatively low and low. Two townships (towns) were randomly selected from each group, and one village was randomly selected from the east, south, west, north and middle of each township. Finally, 8 vegetable farmers were randomly selected from each sampled village. Given the vegetable farmers' level of education, the questionnaires were completed through household interviews. The investigators who conducted these interviews were either trained graduate students or senior undergraduates. In this survey, 400 questionnaires were distributed, and ultimately, 385 valid questionnaires were obtained after eliminating the missing key information, with multiple choices given for a single choice question and irrelevant content. The effective response rate of the questionnaires was 96.25%.

4.3. Descriptive statistics of characteristic variables

Of the 385 vegetable farmers surveyed in this survey, 94 had adopted GCT, accounting for 24.4% of the surveyed farmers, which is consistent with the low GCT adoption rate in China; 266 farmers participated in cooperatives, accounting for 69.1% of the farmers. The average risk aversion of the vegetable farmers was 0.637 (Table 2).

Table 2
Descriptive statistics of variables.

Variable type	Variable	Measure	Mean	Std. dev.
Dependent variable	GCT adoption	1 = adoption; 0 = nonadoption	0.234	0.424
Central independent variable	Cooperative membership	1 = member; 0 = nonmember	0.691	0.463
	Risk aversion degree	Risk aversion parameter (σ)	0.637	0.885
Controlled variable	Age	Actual age in 2017	47.187	26.247
	Gender	1 = male; 0 = female	0.608	0.489
	Education degree	Years of education	7.846	3.196
	Farm size	Farm area in 2017 (mu)	6.214	3.587
	Share of non-agricultural income.	The ratio of a farmer's non-agricultural income to his/her total household income in 2017	0.274	0.323
	Number of laborers	Number in family farming in 2017	3.449	1.987
	Frequency of communication with neighbors	The average number communications with neighbors each week	10.324	5.324
	Participation in training	1 = participation; 0 = nonparticipation	0.283	0.451
	Social capital	Social capital index	0.407	0.288
	Land tenure	1 = the farmer has transferred land and has not signed a written contract with a transfer term of three years or more; 2 = the farmer has transferred land and has signed a written contract with a transfer term of three years or more; 3 = the farmers has not transferred the land	2.308	1.486
Identification variable	Distance to the nearest cooperative	Actual distance to the nearest cooperative (km)	5.025	3.153

Regarding gender, 234 household heads are male, accounting for 60.8% of the surveyed farmers. The farmers' average age is between 47 and 48 years, which clearly shows the aging trend of the household head. The average farmer has less than 9 years of education, which indicates that the average level of education for household heads is low. Regarding the number of laborers and farm size, all of the farms are family operations. The average number of family members farming is between 3 and 4, and the average farm size is between 6 and 7 mu. Based on the above indicators, the results of this survey are essentially consistent with the third agricultural census of Shandong Province, which indicates that the results of this survey are representative.

In addition, the average share of non-agricultural income of vegetable farmers is 0.274, and they mainly produce vegetables that are common in the market, such as cabbage, cucumber and tomatoes. They plant for one or two seasons a year and face relatively serious pest and disease attacks.

4.4. Descriptive statistics on vegetable farmers' degree of risk aversion

As shown in Fig. 1, sample vegetable farmers with a risk aversion coefficient less than 0 accounted for 14.29% of the total, while 330 of the sampled vegetable farmers (85.71%) had a risk aversion coefficient greater than 0, which indicates that most of the sample farmers were risk averse. Among the risk-averse farmers, 88 had a risk aversion coefficient between 0 and 0.5 accounting for 28.86% of the total; 108 had a risk aversion coefficient between 0.5 and 1, accounting for 28.05% of the total; and 134 farmers had a risk aversion coefficient greater than 1, accounting for 34.80% of the total. This indicates that the risk-averse farmers are typically highly risk averse and that the lower the level of risk aversion considered, the fewer farmers observed. This is close to the distribution of farmers' risk aversion coefficient studied by Ihli et al. (2016), which may indicate that the measure of vegetable farmers' risk aversion in this experiment exhibits high reliability.

4.5. Comparison between cooperative members and nonmembers in terms of average risk aversion and GCT adoption behavior

As shown in Table 3, among the vegetable farmers who participated in cooperatives, 65 adopted GCT. In contrast, among those who did not participate in cooperatives, only 29 adopted GCT, which may indicate that vegetable farmers who participate in cooperatives are more likely to adopt GCT than those who do not.

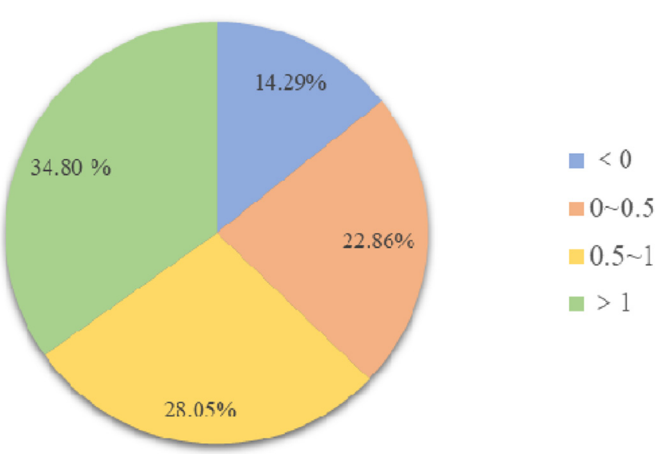

Fig. 1. Interval distribution of vegetable farmers' risk aversion coefficient.

Second, among vegetable farmers who participate in cooperatives, the average level of risk aversion for those who do and those do not adopt GCT is 0.562 and 0.621, respectively. Among vegetable farmers who do not participate in cooperatives, the average degree of risk aversion among those who adopt GCT is 0.358, while that for those who do not adopt GCT is 0.791. Regardless of whether vegetable farmers participate in cooperatives, the average degree of risk aversion among those who do not adopt GCT is higher than that among farmers who adopt GCT. This result may indicate that the probability of adopting GCT decreases in vegetable farmers' degree of risk aversion. Third, among vegetable farmers who adopt GCT, the average degree of risk aversion among those who participate in cooperatives is higher than that among farmers who do not participate, and the number of vegetable farmers who participate in cooperatives was significantly higher than the number who do not. This result may mean that vegetable farmers' participation in cooperatives can to some extent offset the impact of risk aversion on GCT adoption behavior.

5. Results

As shown in Table 4, the correlation coefficient between the random error term of the switching equation and the outcome equation is significantly nonzero at the 1% level, indicating that cooperative membership is an endogenous variable. Therefore, the switching and outcome equations cannot be estimated independently. It is necessary to construct an ESPM.

5.1. Determinants of vegetable farmers' cooperative membership

According to the estimation results of the switching equation in the ESPM, the impact of vegetable farmers' risk aversion on cooperative membership is significant and positive: H2 is supported.

In addition, the gender and education of the household head, farm size, participation in training and social capital significantly and positively affect the likelihood of vegetable farmers becoming cooperative members. However, the age of the household head, the number of laborers, land tenure and distance to the nearest cooperative are significantly and negatively associated with vegetable farmers' cooperative membership. These findings are consistent with the above expectations and essentially consistent with those of Mojo et al. (2017). Furthermore, the frequency of communication with neighbors and share of non-agricultural income does not significantly influence vegetable farmers' likelihood of holding cooperative membership. The possible explanations are as follows. First, neighbor communications in China are mostly practiced as chatting after eating. Second, non-agricultural income is not the main economic resource of the sample vegetable farmers. The non-agricultural income of vegetable farmers accounts for a relatively low proportion of income, and differences based on the level of non-agricultural income are not obvious.

5.2. Determinants of vegetable farmers' GCT adoption behavior

According to the estimation results from the outcome equation in the ESPM, vegetable farmers' degree of risk aversion has a significant and negative impact on the adoption of GCT; H1 is supported. However, being a member of a cooperative has a significant and positive association with vegetable farmers' GCT adoption; thus, H3 is supported.

In addition, among the control variables, the gender of the household head, level of education, farm size, participation in training, social capital and land tenure significantly and positively affect vegetable farmers' GCT adoption. The age of the household head and the number of laborers significantly and negatively

Table 3
Comparison between cooperative members and nonmembers on average risk aversion and GCT adoption behavior.

Cooperative membership	GCT adoption behavior	The number of vegetable farmers	Average risk aversion
Cooperative members	GCT adoption	65	0.562
	GCT nonadoption	201	0.621
Cooperative nonmembers	GCT adoption	29	0.358
	GCT nonadoption	90	0.791

Table 4
The estimation results of the endogenous switching probit model.

Variable type	Variable	The switching equation (Cooperative membership)	The outcome equation (GCT adoption behavior)
□ Central independent variable	Cooperative membership	–	1.121[c](0.283)
	Risk aversion degree	0.513[c](0.106)	−1.148[c](0.306)
Controlled variable	Age	−0.039[b](0.019)	−0.032[c](0.022)
	Gender	0.249[a](0.164)	0.206[a](0.118)
	Education degree	0.212[c](0.036)	0.154[b](0.062)
	Farm size	0.024[a](0.013)	0.037[b](0.015)
	Number of laborers	−0.042[a](0.045)	−0.177[b](0.081)
	Share of non-agricultural income	−0.172 (0.057)	−0.094 (0.062)
	Frequency of communication with neighbors	0.025 (0.023)	0.038 (0.029)
	Participation in training	0.214[c](0.029)	0.176[c](0.054)
	Social capital	0.174[c](0.036)	0.142[c](0.078)
	Land tenure	−0.125[a](0.032)	0.187[b](0.092)
Identification variable	Distance to nearest cooperative	−0.811[c](0.173)	–
Correlation coefficient	ρ	–	0.317[c](0.096)
	Constant	−3.173[c](0.412)	−4.934[c](0.688)
	Observations	385	

[a] Denotes significance at 10%.
[b] Denotes significance at 5%.
[c] Denotes significance at 1%.

Table 5
Decomposition of the impact of vegetable farmers' risk aversion on GCT adoption behavior.

The impact type of risk aversion	Calculation	Result
Direct impact	γ_2	−1.148
Indirect impact	$\gamma_1\theta$	0.575
Total impact	$\gamma_2+\gamma_1\theta$	−0.573

impact vegetable farmers' GCT adoption. These findings are consistent with the above expectations and essentially consistent with those of Gao et al. (2017a). Furthermore, the frequency of communication with neighbors and the share of non-agricultural income does not significantly influence vegetable farmers' GCT adoption; the reasons are consistent with the discussion in section *5.1.*

5.3. The impact of cooperative members on the inhibitory effect of risk aversion on GCT adoption

As shown in Table 5, according to the estimation results of the ESPM, $\gamma_2 =$ -1.148, $\gamma_1 = 0.513$, and $\theta = 1.121$. The direct effect of the risk aversion of vegetable farmers on GCT adoption behavior is −1.148, the indirect effect is 0.513, and the total impact is $(\gamma_2 + \gamma_1\theta)= (-1.148 + 0.513 \times 1.121) =$ -0.573. H4 is supported.

6. Discussion

In this study, an endogenous switching probit model was constructed to analyze the impact of vegetable farmers' risk aversion and cooperative membership on their adoption of green control techniques. Furthermore, it examines whether cooperative membership helps alleviate the inhibitory effect of risk aversion on the adoption of green control techniques among vegetable farmers. The estimated results revealed that:

6.1. Risk aversion has a positive impact on farmers' participation in cooperatives

This is consistent with the research conclusions of Zheng et al. (2012) which took farmers in northern China as an example, and Duguma (2016) which took farmers in Ethiopia as an example. In the survey, when asked what help cooperatives provide, some vegetable farmers said, "cooperatives provide us with group agricultural insurance, improved varieties of vegetables, and technical guidance services, which greatly reduce natural risks and production risks"; other vegetable farmers said that cooperatives offer "'elite' guidance on vegetable sales. Cooperatives also provide us with a wider choice of sales channels than when they sell individually. Cooperatives also make common vegetable purchases through agreements with us, and when they establish sales contacts with supermarkets and leading companies, they each secure part of the contract, which greatly reduces sales risks". Cooperatives thus may help vegetable farmers reduce natural risks, production risks and sales risks; therefore, vegetable farmers with high risk aversion may tend to participate in cooperatives.

6.2. Risk aversion has a negative impact on farmers' GCT adoption behavior

This is consistent with the research conclusions of Ward and Singh (2015) which took farmers in India as an example, and Gao et al. (2017a) which took farmers in the Huang-huai-hai Plain of China as an example. In the interviews, some vegetable farmers clearly stated that although the adoption of GCT can guarantee the quality of agricultural products, safe agricultural production and environmental safety, they were unlikely to adopt GCT due to risk considerations.

6.3. Participation in cooperatives has a positive impact on farmers' GCT adoption behavior

This is consistent with the research conclusions of Wossen et al. (2017) which took farmers in Nigeria as an example, and Ma et al. (2018) which took farmers in China as an example. The possible explanations for this impact are as follows. First, cooperatives provide vegetable farmers with production material procurement services, credit guarantee services and shared vegetable purchasing services, which not only enable them to obtain high-quality production materials at low prices but also facilitate credit access and timely sales, thereby allowing them to reduce production, credit and liquidity constraints. Second, through the provision of information consultation services, cooperatives enable the vegetable farmers to obtain GCT information more quickly and accurately, improve their understanding of GCT, and enhance their perceptions of the usefulness and ease of use of GCT, which facilitates their acceptance of GCT. Third, cooperatives not only provide GCT guidance services to vegetable farmers but also regularly organize GCT communication activities among them, so that vegetable farmers can adroitly master the skills needed for GCT operations and reduce the risk that they will improperly use techniques. Fourth, cooperatives provide group agricultural insurance for vegetable farmers. When faced with sudden pest and disease outbreaks, vegetable farmers can secure their right to benefits through this agricultural insurance and obtain compensation, thus enhancing their ability to resist natural risks. Clearly, cooperative participation reduces the riskiness of production, operations and sales for vegetable farmers. Based on this, vegetable farmers may experience reduced risk aversion towards adopting GCT, and when they make a GCT adoption decision, they will be more likely to choose to adopt when offered help by cooperatives.

6.4. Farmers' membership in cooperatives can alleviate the inhibitory effect of risk aversion on GCT adoption behavior

These results indicate that the direct effect of farmers' risk aversion on GCT adoption behavior is greater than the indirect effect. Thus, vegetable farmers' participation in cooperatives may help alleviate the inhibitory effect of risk aversion on GCT adoption behavior, reducing it by 50.09%

7. Conclusions

The main conclusions of this paper are as follows. First, vegetable farmers' degree of risk aversion has a significant and positive impact on their cooperative membership and a significant and negative impact on their GCT adoption behavior. Second, vegetable farmers' cooperative membership may not only promote their adoption of GCT but also alleviates the inhibitory effect of their risk aversion on GCT adoption.

The extension and application of GCT are important for the development of cleaner and more sustainable agriculture; the finding that farmers' membership in cooperatives can alleviate the inhibitory effect of risk aversion on GCT adoption behavior requires more attention. The main conclusions of this paper lead to the following policy implications for the formulation of GCT extension policies. First, the risk of adopting GCT should be reduced for farmers. Policymakers should gradually establish a monitoring and early warning system for production, supply and demand, and price setting for major agricultural products; they should eliminate trade information barriers in the agricultural products market and vigorously develop contract farming to establish an effective market linkage to reduce the risks experienced by farmers. At the same time, increasing farmers' access to technical training reduces the risk that they will inappropriately use technology. The second policy implication is that support for cooperatives should be strengthened, for example, by increasing financial support for cooperatives and thereby alleviating the expense of providing information and consulting on technology, production and other services, particularly among cooperatives with high debt levels. Financial support could include relaxing the maximum loan limit for cooperatives, thereby reducing the financial constraints that they face; increasing support for talent development for cooperatives by conducting regular training for key members, guiding college graduates to work in cooperatives, encouraging eligible cooperatives to hire professional managers, and alleviating constraints on the talent at cooperatives. The third policy implication is that the internal conditions and external environment should be improved to encourage farmers to adopt GCT. The household head's gender, level of education, farm size, participation in training, social capital and land tenure significantly and positively affect vegetable farmers' GCT adoption. The age of the household head and number of laborers significantly and negatively impact vegetable farmers' GCT adoption. Policymakers should cultivate the self-learning ability of farmers, and nonformal education should be actively adopted to improve their education level. Policymakers should also establish and improve rural land circulation and trading, improve relevant laws and regulations, enable farmers to achieve moderate-scale operations, and effectively ensure land tenure security. To address training, they can design personalized training programs, explore participatory visual teaching and training methods, and improve the training effect. Finally, efforts can include strengthening rural informatization and infrastructure construction and paying attention to the cultivation of farmers' social capital; for females, elders and households with more laborers, publicity efforts should be intensified, and increased subsidies should be provided to eliminate their resistance and concerns and encourage them to take the initiative to adopt GCT.

GCT is the localized version of IPM in China. Similar to China, other developing countries are also facing the challenges of chemical pesticide overuse and low levels of IPM adoption. Furthermore, the perceived risks of IPM adoption by farmers and the resulting aversion are also common in other developing countries. Thus, this study's analytical framework is applicable to other developing countries, and the conclusions may have important implications for these countries as they implement IPM promotion policies.

Of course, there are some limitations in this paper. Future research directions are as follows: First, the research conclusions of this paper are based on vegetable farmers in Shandong Province, but whether consistent research conclusions can be drawn in other parts of China remains to be verified. Second, GCT is a complex technology package that includes multiple sub-technologies. This paper only investigates whether farmers adopt GCT. In further studies, specific GCT sub-technologies can be incorporated into the analysis framework to further explore the deep role of cooperative membership.

CRediT authorship contribution statement

Lili Yu: Conceptualization, Methodology, Investigation, Formal analysis, Writing - original draft, Supervision, Writing - review &

editing, Validation. **Chen Chen:** Methodology, Writing - review & editing, Software, Validation. **Ziheng Niu:** Methodology, Writing - original draft, Software. **Yang Gao:** Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Project administration, Writing - original draft, Resources, Funding acquisition, Supervision, Writing - review & editing, Software, Validation. **Haoran Yang:** Writing - original draft, Validation. **Zihao Xue:** Writing - review & editing, Validation.

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.

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