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Multi-Level Determinants of Acceptance in Centralized Pesticide Delivery among Farmers: Evidence from Huangshan City, China

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Abstract: Highly toxic pesticides bring negative externalities to water pollution, which increase the demand for green pesticides that are low-toxic and high-efficiency. With the implementation of the unique the Centralized Pesticide Distribution (CPD) policy aiming to reduce the use of chemical pesticides in Huangshan, we try to explore the factors that affect farmers' acceptance of CPD and thus change their pesticides selection. Based on the theory of farmers' ecological rationality, we build a decision-making ecosystem on accepting CPD and assuming that farmers' behavior is determined hierarchically by factors, then the Logistic-AISM model is used for empirical testing using data collected from 233 representative farmers. The results show that the proportion of agri-income and participation in cooperatives fundamentally affected choices for CPD acceptance through two middle-level indirect factor: government publicity and the availability of agri-information by changing farmers' cognition on pesticides and production status. Thus, CPD may be improved by selling a richer variety of insecticides and implementing more publicity. Lessons from China inspire other intensive farming countries to promote green pesticides by: expanding the sales channel of green agri-products, playing the auxiliary role of cooperatives, and inventing more eco-friendly pesticides.

Keywords: Centralized Pesticide Delivery; green pesticide; farmer's behavior; water pollution management; ecological rationality; Logistic-AISM model

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1. Introduction

Pesticides play a safeguarding role in agricultural production to protect crops and ensure productivity [1]; however, the intensive use of farmland asks for massive application of chemical products, including pesticides [2]. The level of pesticide use has been growing rapidly in both developing and developed countries [3]; the worldwide consumption of pesticide reached nearly 4.2 million tons in 2019, an increase of 34.54% compared with 20 years ago [4]. The overuse of pesticide brings enormous negative externalities that damage human well-being by threatening the water quality, causing agricultural non-point source pollution and impeding the sustainable development of agriculture [5–7]. To cater the demand for reducing agricultural sewage and the goal of global sustainable development, farmers need to gradually switch their selections to more suitable and eco-friendly pesticides, which is supported by domestic and international policies [8,9].

As the largest developing country and the second biggest agricultural trader, China faces the severe problem of massive use of chemical pesticides due to intensive farming. In response, the government of China has issued a series of policies and achieved the goal of zero growth in pesticides in 2020. However, the concern of overusing has not yet been fundamentally resolved, which can be seen according to the latest data that the unit of pesticide used in China in 2019 was 13.07 kg/ha, almost five times as high as the world level [10]. The hidden drives behind it are smallholder's high reliance on chemical reagents and their bounded rationality of making decisions [11,12]. Considering that after traditional chemical pesticides are used in farmland, it is difficult for the residual organic compounds to be decomposed naturally, thus they will flow into groundwater through soil infiltration or into surface water through rainwater scouring, eventually causing water pollution, prompting farmers to use low-toxic, eco-friendly pesticides is of great significance to water pollution control.

Among various pesticide reduction policies and measures, an innovative policy called "Centralized Pesticide Delivery" (hereinafter called "CPD") emerged in Huangshan City, Anhui Province, which was inspired by the idea of eco-compensation to guide farmers to use eco-friendly pesticides [13]. With the support of CPD policy, the large-scale family farm can order high-efficiency and low-toxic green pesticides at the ex-factory price from an agricultural material company selected by the government through bidding; smallholders can buy green pesticides at the same price from retail stores that cooperate with the company. The company and retail stores gain eco-compensation from government, accounting for 22% of the turnover. Types of pesticides that the company could sell are determined by agrotechnical experts based on the local planting circumstances annually. In the latest 2021, CPD provides a total of 354 pesticides in five categories. Table 1 shows the specific data and the representative products of each category. It can be seen that on the one hand, CPD provides various specifications of new low-toxicity and high-efficiency biological pesticides; on the other hand, it also ensures the supply of physical control tools such as live bees and insect traps.

Table 1. Pesticides and representative products offered by CPD in X County in 2021.

Category	Types	Active Ingredients of Representative Products	Variety of Representative Products	Concentration (%)
Insecticide	122	Emamectin Benzoate	13	0.6–5.7
Fungicide	99	Benzoic Propiconazole	6	30–50
Herbicide	117	Glyphosate	40	30–88.8
		Glufosinate ammonium	36	10–88
Growth regulator	4	Brassinolide	2	0.01
Plant protection products	12	Sex attractant	4	-
		Live insect and mites	2	-
		Insect trap	6	-

Building a CPD system such as this one, the local governments try to drive farmers to switch their choice of pesticides to ensure food safety and control agricultural water pollution in origin. The incentives provided by CPD to farmers include, firstly, cheaper price (25% lower than the market price on average); secondly, more efficient and more complete range of eco-friendly pesticides; thirdly, the improvements in the quality and selling price of agricultural products through using these pesticides.

Facts have proved that CPD has indeed produced remarkable results in improving water quality. The Xin'an River, whose main stream is 373 km long and has a drainage area of more than 11,000 square kilometers, originates from X County, flows eastward into Zhejiang Province, and joins Qiandao Lake. Faced with the huge pressure of water quality protection, since the implementation of CPD, the annual average value of each monitoring index of water quality status in X County has reached or exceed the Class II surface water environmental quality standard. As for the downstream Qiandao Lake, it transports more than 6 billion cubic meters of clean water every year, which makes the water quality of Qiandao Lake reach Class I, and the nutritional status index changes from mesotrophic to oligotrophic. With such achievements, analyzing the determinants that affect farmers' acceptance of CPD can provide new inspiration for the management of pesticide dosage and water pollution.

Whether a farmer adopts CPD and buys green pesticide from it is an individual's pesticide selection behavior driven by his interests and influenced by his own characteristics and the surrounding objective environments (natural, economic, social). So far, a growing number of studies have explored the deciding factors that influence farmers' pesticide selection behavior. The previous literature mainly focuses on the influence of internal determinants on the selection behavior of pesticides, such as individual and family characteristics [14–16], cognition and awareness [17], psychological determinants, and planting characteristics of farmers [18,19]. Some scholars have also started to conduct research in the external environment, from technical training, policy factors and other aspects [20,21]. The commonly used models include Logistic, Probit, Threshold regression, etc. However, their studies may be more reasonable if the hierarchical structure between the various determinants and their mechanism of action are taken into consideration.

In terms of research objects, due to the innovative nature of the CPD policy and its geographical restrictions (only implemented in Huangshan City), there has not been any research to analyze the determinants of farmers' adoption of CPD. Therefore, it is imperative to have a fine-grained understanding of the mechanism of farmer's adaption behavior to maximize the function of CPD, thereby ensuring food safety and controlling agricultural water pollution. Therefore, the objectives of the current study are as follows:

1. What factors affected farmers' decision to adopt CPD?
2. What is the internal relationship and hierarchical structure between these factors?
3. How can the current CPD policy be improved? What lessons can CPD offers to other regions for pesticide reduction and water pollution management?

Inspired by the existing research, we first constructed a theoretical framework for the differences in farmers' adoption of CPD based on the theory of bounded rationality, then use binary logistic model and AISM (Adversarial Interpretive Structure Modeling) method to identify determinants' multi-level feature. The empirical analysis used survey data collected in July 2021 from 233 farmers from Huangshan. The findings are anticipated to obtain useful implications for improving the CPD and propose a paradigm to encourage farmers to use high-efficiency and low-toxic pesticides.

The remainder of this study is organized as follows: Section 2 presents the theoretical framework and methods, and Section 3 introduces the empirical results and their interpretation, which will be further discussed in Section 4.

2. Theoretical Analysis and Methods

2.1. Theoretical Framework

The acceptance of CPD by farmers is actually a question of decision-making. In the view of neoclassical economics, farmers tend to follow the principle of "economic rationality" and obtain the greatest income at the least cost, whereas relevant studies in behavioral economics have shown that under uncertainty, people's decision-making not only contradicts the expected utility theory [22], but also leads to framing effect [23]. With limited cognitive ability, decision makers often display "bounded rationality" and prefer satisfactory choices rather than optimal ones. Further, Todd put forward the concept of "ecological rationality"; that is, people make their decisions relying on an "ecosystem" where internal cognition and external environmental information interact together [24].

Based on our field survey, we accept Todd's view and consider that farmers are "ecological rational". Whether or not to purchase pesticides through CPD is subject to the dual constraints of internal cognitive structure and external environment (including neighbors, cooperatives, government and so on). In this study, referring to the relevant literature on pesticide selection behavior [25–27], the determinants of acceptance CPD by farmers are roughly divided into four parts, including individual characteristics, household business, cognitive abilities, and external environmental information. We believe that under the restriction of this complex and changeable multi-level decision-making ecosystem, farmers may take different moves in adopting CPD due to the deviation of ecological rationality.

Individual characteristics. The features of farmers, containing factors such as age, education level, and cadre experience, influence their choice on adopting CPD. Generally, age is a related factor to distinguish the types of pesticides used by farmers [28]. Older farmers are more likely to choose high-toxic pesticide, while younger adults tend to try new green pesticide. Peasants with higher education level may be more willing to use low-toxic pesticides, based on richer knowledge accumulation [29]. Additionally, people with cadre experience have a wider understanding of policies, so they should be more motivated to respond to the CPD policy.

Household business. As a member of the family, when making productive decisions such as pesticide selection, household's income risks and expected benefits should be considered. For instance, since many farmers blindly equate "low-toxic" with "low efficiency", they believe that green pesticides require higher frequency of spraying and therefore cost more human capital [30]. In this case, the greater number of family members engaging in agri-production, the more capable they are of avoiding losses; therefore, they may try the green pesticides offered by CPD. Besides, for families who make a living mainly from agriculture, the improvement of crop quality caused by the application of biological and green pesticides can bring them higher expected benefits, which positively encourages them to adopt CPD [31]. Moreover, the family planting size and soil quality can also affect farmer's selection. For those with large planting scale and fertile land, their expected income risks are smaller, and thus they are more open to choose low-toxic green pesticide [32].

Cognitive abilities. Bell thinks that the complex psychological factors such as "cognition" are pivotal in farmer's decision-making behavior [33]. There are roughly two types of cognition that we focus on. The first is risk awareness, including the awareness of pest risk and disease risk. The farmers who believe that their own agricultural products will more easily get sick and attract pests will conservatively select high-toxic pesticides to ensure yield [34]. The second is the cognition of pesticide-related knowledge, such as the damage to health and environment pollution caused by pesticides. The high level of pesticide-related cognition means easier adoption to CPD. On the contrary, farmers who lack of cognition are likely to randomly choose high-toxic pesticide [35].

External environmental information. The prospect theory proposed by Tversky [23] believes that new information given to individuals by the external environment will shape a brand-new decision-making scenario and thus impact human behavior. Hence, we add five external environmental determinants, namely neighbors, cooperatives, information acquisition, agri-technical training, and government publicity, to analyze farmer's pesticide selection after receiving information from them. Surprisingly, some studies agreed that, compared with economical rational people who want to collect as much information as possible, ecological rational decision makers prefer to gain less amount but more important information [24]. Under the behavioral principle of information-saving, the input of external environmental information may have an unexpected impact on farmer's decision making.

2.2. Methods

2.2.1. Logistic Model

Logistic model is a generalized linear regression method, which has been widely used in psychology, sociology, economics, and so on. In our research, whether farmers adopt CPD policy is obviously a binary decision problem. Therefore, it is appropriate to use Logistic model to explore the determinants of farmers' behavior. The general form of Logistic is as follows:

$$P_K = F\left(\alpha + \sum_{i=1}^{n} \beta_i x_i\right) = \frac{1}{1 + \exp\left[-\left(\alpha + \sum_{i=1}^{n} \beta_i x_i\right)\right]} \tag{1}$$

After converting Equation (1) into logarithmic transformation, the linear expression of the binary Logistic model is as follows:

$$Y = \ln\left(\frac{P_k}{I - P_k}\right) = \alpha + \sum_{i=1}^{n} \beta_i x_i \tag{2}$$

In Equations (1) and (2), k is the number of observations. P_k represents the probability that the k-th sample accepted CPD, hence, $1 - P_k$ means the probability that it did not accept CPD. α is the intercept term. x_i are factors that may affect farmer's pesticide selection, β_i is the corresponding regression coefficient. In combination with the variable selection mentioned above, the value of i is (1, 2, . . . , 16) respectively.

2.2.2. Adversarial Interpretive Structure Model

Despite of the ability of Logistic model to identify significant determinants, the hierarchical relationship between them cannot be presented. Therefore, it is necessary to use the AISM (Adversarial Interpretive Structure Model), a derivative of the ISM (Interpretive Structure Model), for further analysis.

ISM is a model that processes information based on the relationship between determinants and the principle of incidence matrix. It regards determinant factors as "nodes" and presents the causal relationships between factors by using directed lines, applying a "result-oriented" way (or so-called "UP-type") to divide the levels of each factor, so as to intuitively display the internal relationships between factors. It is popular in the analysis of structural problems of complex socio-economic systems because of its clarity [36].

On this basis, AISM introduces the idea of adversarial in the generative adversarial network, which is the latest model proposed to explore the internal structure of determinants [37]. In a nutshell, on the purpose of comprehensively displaying the hierarchy kite between factor, AISM aims to obtain a pair of simplest multi-level topological diagrams through adding the rules "cause-oriented" (so-called "DOWN-type") with UP-type together without losing system function. We accepted the AISM model to discuss in depth the hierarchical relationship between the determinants that affect the acceptance of CPD and build a multi-level topological diagram; the processing flow is outlined in Figure 1.

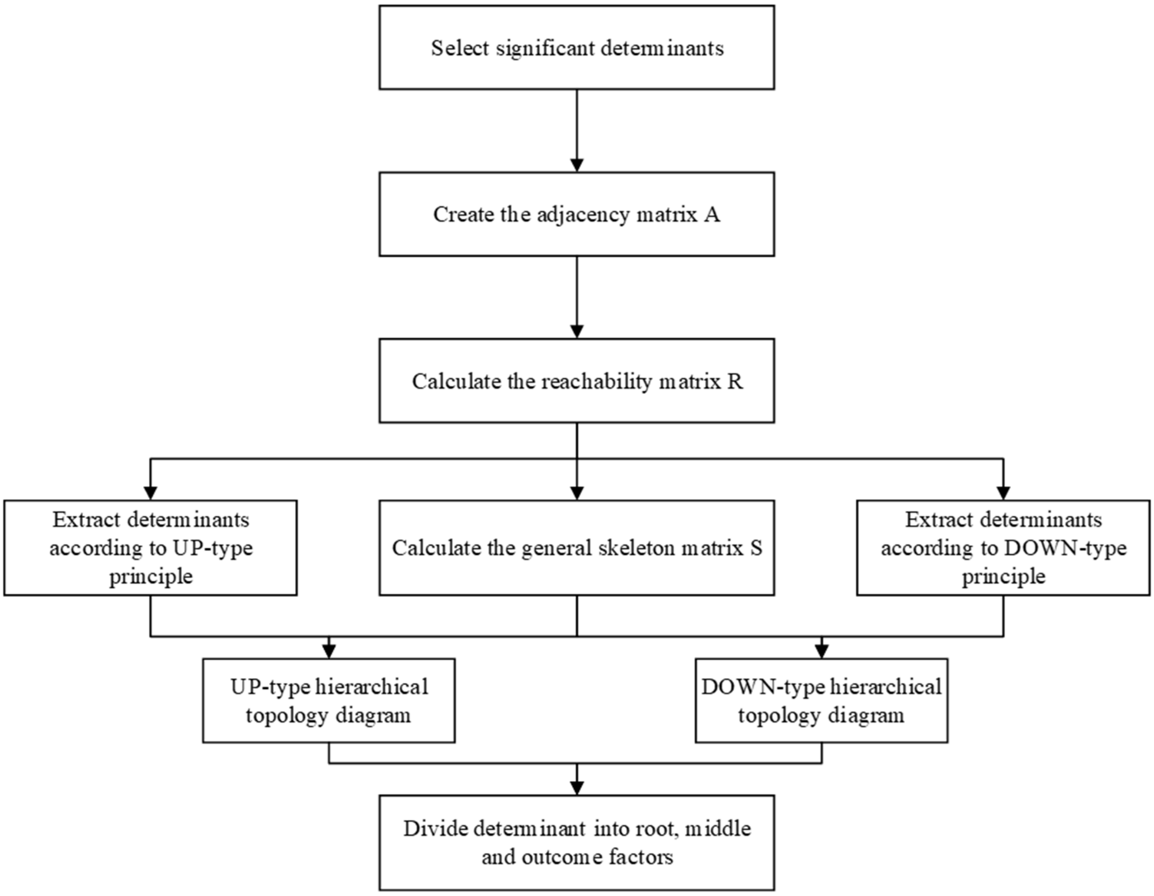

Figure 1. Flowchart of AISM model. The figure shows in detail the five steps of the AISM model.

3. Results

3.1. Varibale and Data

3.1.1. Variable Selection

Based on the theoretical analysis in Section 2, we supposed the dependent variable = 1 if the farmer accepts CPD, otherwise = 0 and assumed the independent variables to be "factors influencing farmer's acceptance behavior", including 16 factors in 4 aspects. Specific variable definitions and descriptive statistics are present in Table 2.

Table 2. Variable definitions and descriptive statistics.

Variable	Description	Mean	S.D.
Age	Age of decision makers for using pesticide (years)	59.1	12.1
Education level	1 = the decision maker has a primary school education or below; 2 = a junior high school education; 3 = a high school education; 4 = a bachelor degree or higher	1.8	0.8
Carde experience	1 = the decision maker has cadre experience, 0 = otherwise	0.3	0.4
Agri-income	Percentage of household agricultural income (%)	0.2	0.3
Agri-laborers	Number of family members who are engaging in agri-production	1.7	0.6
Soil fertility	Evaluation of soil fertility from 1 to 4, 1 = bad, 4 = good	2.5	0.7
Farm size	Total cultivated area in 2020 (ha [1])	0.6	16.7
Risk of pest	Perception of the possibility of crop pest from 1 to 5, 1 = extremely small, 5 = extremely big	3.2	1.5
Risk of plant disease	Perception of the possibility of plant disease from 1 to 5, 1 = extremely small, 5 = extremely big	2.3	1.4
Risk of health	Degree of the health damage by using pesticides from 1 to 5, 1 = extremely small, 5 = extremely big	2.5	1.4
Risk of environment	Degree of the pollution by using pesticides from 1 to 5, 1 = extremely small, 5 = extremely big	3.5	1.3
Neighborhood	The frequency of communicating pesticides with villagers from 1 to 5, 1 = never, 5 = very frequently	3.4	1.5
Cooperatives	1 = the decision maker is a cooperative member, 0 = otherwise	0.3	0.4
Information acquisition	Difficulty of obtaining agri-information from 1 to 5, 1 = very difficult, 5 = very easy	3.5	1.3
Technical training	1 = the decision maker has received agri-technical training, 0 = otherwise	0.3	0.5
Government publicity	1 = the decision maker has received government publicity, 0 = otherwise	0.9	0.4

[1] ha: the abbreviation for hectare.

3.1.2. Data

The CPD policy in Huangshan, Anhui Province, started in 2016, has contributed to the local water quality and food safety. In particular, CPD in Xiuning County has achieved eye-catching results. In 2020, the CPD in Xiuning sold 120.1 tons of green pesticides, accounting for 30% of the county's total demand for pesticides. In April and July 2021, in order to summarize the local pesticide control experience, an Asian Development Bank technical assistance team from China Agricultural University went to Xiuning and collected research-related data from local farmers.

Stratified random sampling is used to select specific survey sites. After checking the 2020 Statistical Yearbook of Xiuning County and the relevant information provided by the local government, we selected 5 towns and randomly visited 2–3 villages in each town for face-to-face interviews (20 farmers per village). The questionnaire is valid only if the respondent is the decision maker for purchasing pesticides in his or her family. Based on this criterion, 7 out of 240 questionnaires were eliminated, and there were a total of 233 credible observations for the survey.

The basic characteristics of interviewers are present in Table 3. Firstly, 33 interviewers said they have never brought pesticides at CPD, accounting for 14.16%. Meanwhile the remaining 200 farmers have purchased pesticide from CPD at least once in 2020, indicating the coverage of CPD in Xiuning County is relatively wide. Secondly, our respondents are mainly 50–70 years old, with an average age of 59. Among them, 70.82% are males and 29.18% are females. Most of the interviewers have only finished their elementary or junior high schools. In addition, 81.12% of farmers have off-farm income. The items mentioned above partly confirm the current status quo of China's rural areas, such as rural aging and the loss of young rural labor force. Therefore, the selected samples are representative. Thirdly, normally most families have 1–2 agricultural laborers (usually the elderly couple), and the smallholders with cultivated area of less than 2 ha account for 96.57%; according to international standards, the two facts jointly confirmed the feature of "smallholder farming" in China's agriculture [38].

Table 3. Basic characteristics of interviewers.

Variable	Description	Respondents	Proportion (%)
Accept CPD	Buy pesticides from CPD at least once	200	85.84
	Never buy pesticides from CPD	33	14.16
Age	Under 40 years old	17	7.30
	40 to 49 years old (including 40 years old)	27	11.59
	50 to 59 years old	77	33.05
	60 to 69 years old	63	27.04
	70 years old or elder	49	21.03
Gender	Male	165	70.82
	Female	68	29.18
Education level	Primary school or lower	102	43.78
	Junior high school	86	36.91
	Senior high school	36	15.45
	Bachelor degree or higher	9	3.86
Off-farm	Families have off-farm income	189	81.12
	Families do not have off-farm income	44	18.88
Farm size	Under 1 ha	215	92.27
	1 to 2 ha (including 1 hectare)	10	4.29
	Above 2 ha	8	3.43

3.2. Estimation of the CPD Accpetance Function

This study used Stata16 for the Logistic regression analysis, with reference to previous research, Probit model is also used for robustness testing. The results from Logistic and Probit model are basically the same, the Wald test values are both significant, and the correct prediction percentages are 90.56% and 90.13%, respectively, indicating the model settings are relatively correct and robust. In addition, the value of VIF is less than 10 (7.87), verifying that there is no multi-collinearity among variables.

The estimation results are shown in Table 4. In the empirical strategy, agri-income, risk of health, risk of environment, cooperative, and government publicity all have significant positive impacts on farmers' acceptance of CPD; meanwhile, risk of pest and information acquisition have a significant negative impact on their behavior. In fact, based on the theory of farmer's ecological rationality, the above determinants not only function independently, but are also interrelated with others, which together constitute a hierarchical decision-making ecosystem for farmers to adopt CPD.

Table 4. Estimation of the CPD acceptance function.

Explanatory Variables	**Logistic Model**			**Probit Model**	
	Coefficient Value	**Odds Ratio**	**Marginal Effect**	**Coefficient Value**	**Marginal Effect**
Age	−0.0194 (0.0225)	0.9808 (0.0221)	−0.0015 (0.0017)	−0.0115 (0.0117)	−0.0016 (0.0017)
Education level	0.0627 (0.3594)	1.0647 (0.3826)	0.0048 (0.0275)	0.0598 (0.1719)	0.0085 (0.0244)
Cadre experience	0.1649 (0.8128)	1.1793 (0.9585)	0.0126 (0.0615)	0.0055 (0.3703)	0.0008 (0.0523)
Agri-income	2.5987 ** (1.3172)	13.4464 ** (17.7110)	0.1979 ** (0.0948)	1.2970 ** (0.6600)	0.1834 ** (0.0896)
Agri-laborers	0.2085 (0.3644)	1.2318 (0.4489)	0.0159 (0.0279)	0.1397 (0.1870)	0.0198 (0.0266)
Soil fertility	0.1073 (0.3094)	1.1132 (0.3445)	0.0082 (0.0235)	0.0388 (0.1609)	0.0055 (0.0227)
Farm size	0.0083 (0.0286)	1.0084 (0.0288)	0.0006 (0.0022)	0.0069 (0.0146)	0.0010 (0.0021)
Risk of pest	−0.5383 *** (0.2074)	0.5837 *** (0.1211)	−0.0410 *** (0.0144)	−0.2687 *** (0.0991)	−0.0380 *** (0.0131)
Risk of plant disease	0.1621 (0.1930)	1.1760 (0.2270)	0.0123 (0.0147)	0.0888 (0.0934)	0.0126 (0.0132)
Risk of health	0.5204 * (0.2877)	1.6827 * (0.4841)	0.0396 * (0.0208)	0.2682 * (0.1374)	0.0379 ** (0.0187)
Risk of environment	0.7682 *** (0.2966)	2.1558 *** (0.6395)	0.0585 *** (0.0215)	0.4118 *** (0.1445)	0.0582 *** (0.0196)
Neighborhood	−0.0917 (0.2389)	0.9124 (0.2180)	−0.0070 (0.0182)	−0.0420 (0.1095)	−0.0059 (0.0155)
Cooperative	1.4142 * (0.7884)	4.1133 * (3.2430)	0.1077 * (0.0605)	0.7134 * (0.3870)	0.1009 * (0.0543)
Information acquisition	−0.4726 * (0.2600)	0.6234 * (0.1621)	−0.0360 * (0.0201)	−0.2585 ** (0.1221)	−0.0365 ** (0.0176)
Technical training	0.2591 (0.6851)	1.2958 (0.8878)	0.0197 (0.0517)	0.0622 (0.3310)	0.0088 (0.0466)
Government publicity	3.4201 *** (0.6479)	30.5744 *** (19.8078)	0.2604 *** (0.0409)	1.9087 *** (0.3226)	0.2699 *** (0.0388)
Constant	−1.5288 (2.5673)	0.2168 (0.5565)	-	−0.8117 (1.3491)	-
Observation	233	233	233	233	233
Wald	43.87 ***	-	52.68 ***	-	
Pseudo R2	0.3679	-	0.3675	-	
Correctly classified	90.56%		-	90.13%	-

Notes: ***, **, * indicate statistical significance at the 1%, 5% and 10% levels respectively. The value in brackets is the robust standard error.

3.3. *AISM Analysis of the Determinants of Accepting CPD*

Through the regression analysis, seven determinants that significantly affected the acceptance of CPD by farmers were selected into the AISM model. They are: agri-income, risk of pest, risk of health, risk of environment, cooperative, information acquisition, and government publicity. Renaming them to X_1-X_7 respectively, according to Figure 1, the calculation process of AISM is presented as follows:

(1) Create the adjacency matrix A. Based on detailed investigations and consultation with experts from Xiuning County Agricultural Technology Station, the Delph method was used to define the logical relationship between the chosen significant determinants. Then, the adjacency matrix A (Table 5) was created according to Equation (3) where m and n = 1, 2, . . . , 7.

$$A_{mn} = \begin{cases} 1, & \text{when} X_m \text{affects} X_n \\ 0, & \text{when} X_m \text{doesn't affect} X_n \end{cases} \tag{3}$$

Table 5. The adjacency matrix A.

$A_{7\times7}$	X_1	X_2	X_3	X_4	X_5	X_6	X_7
X_1	0	0	0	0	1	0	0
X_2	0	0	0	0	0	0	0
X_3	0	0	0	1	0	0	0
X_4	0	0	1	0	0	0	0
X_5	1	0	1	1	0	1	1
X_6	0	1	1	1	0	0	1
X_7	0	0	1	0	0	0	0

Notes: X_1–X_7 are respectively: agri-income, risk of pest, risk of health, risk of environment, cooperative, information acquisition and government publicity. In the Tables 6–8 next, X_1–X_7 has the same meaning.

(2) Calculate the reachability matrix R. In line with Equation (4), the reachability matrix R can be calculated.

$$R = (A + I)^{\lambda+1} = (A + I)^{\lambda} \neq (A + I)^{\lambda-1} x \tag{4}$$

where $2 \leq \lambda \leq 7$, I mean the unit matrix and the exponentiation of matrix adopts the Boolean algorithm.

For matrix R (Table 6), there are reachable set Re, prior set Qe, and common set Te, corresponding to the matrix R. Re represents a set of determinants that can be reached from Xm, whereas Qe represents a set of determinants that can reach Xm. The intersection of Re and Qe is called Te, and the mathematical expression is: Te = Re ∩ Qe.

Table 6. The reachability matrix R.

$R_{7\times7}$	X_1	X_2	X_3	X_4	X_5	X_6	X_7
X_1	1	1	1	1	1	1	1
X_2	0	1	0	0	0	0	0
X_3	0	0	1	1	0	0	0
X_4	0	0	1	1	0	0	0
X_5	1	1	1	1	1	1	1
X_6	0	1	1	1	0	1	1
X_7	0	0	1	1	0	0	1

(3) Extract determinants hierarchically. As stated in Section 2, there are two complementary hierarchical extraction rules in AISM, namely UP-type and DOWN-type, to obtain UP-type and DOWN-type topological hierarchy diagram, respectively. The detailed extraction steps are: the rule of Te = Re is followed in UP-type, the final result determinants are extracted and placed on the top layer, then others determinants are sequentially placed until the bottom tier. On the contrary, in the DOWN-type, the rule of Te = Qe is applied to cramp out the root cause determinants and place them at the bottom layer at first, then orderly extract others upward until the top tier. See Table 7 for the adversarial hierarchy extraction results.

Table 7. Adversarial hierarchy extraction results.

Levels	UP-Type (Result-Oriented)	DOWN-Type (Reason-Oriented)
Level 1	X_2, X_3, X_4	X_3, X_4
Level 2	X_7	X_2, X_7
Level 3	X_6	X_6
Level 4	X_1, X_5	X_1, X_5

(4) Calculate the general skeleton matrix S. At the same time, in order to eliminate the repetitive information, it is necessary to compress matrix R (shrink its nodes and lines) according to Equation (5) to obtain the skeleton matrix S′.

$$S' = R' - (R' - 1)^2 - 1 \tag{5}$$

Then, expand matrix S′ by adding the compressed nodes to obtain a general skeleton matrix S (Table 8).

Table 8. The general skeleton matrix S.

$S_{7\times 7}$	X_1	X_2	X_3	X_4	X_5	X_6	X_7
X_1	0	0	0	0	1	0	0
X_2	0	0	0	0	0	0	0
X_3	0	0	0	1	0	0	0
X_4	0	0	1	0	0	0	0
X_5	1	0	0	0	0	1	0
X_6	0	1	0	0	0	0	1
X_7	0	0	1	0	0	0	0

(5) Draw topological hierarchy diagram. Combining the results (Tables 7 and 8), the topological hierarchy diagrams are drawn as follows (Figure 2). The left side of Figure 2 is the UP-type topological hierarchical diagram, and the right side is the DOWN-type diagram. The reachability relationships between the significant determinants of farmers accepting CPD is represented by directed line segments. In the diagram, the determinants at the lower levels are more rooted, and the upper determinants are relatively superficial.

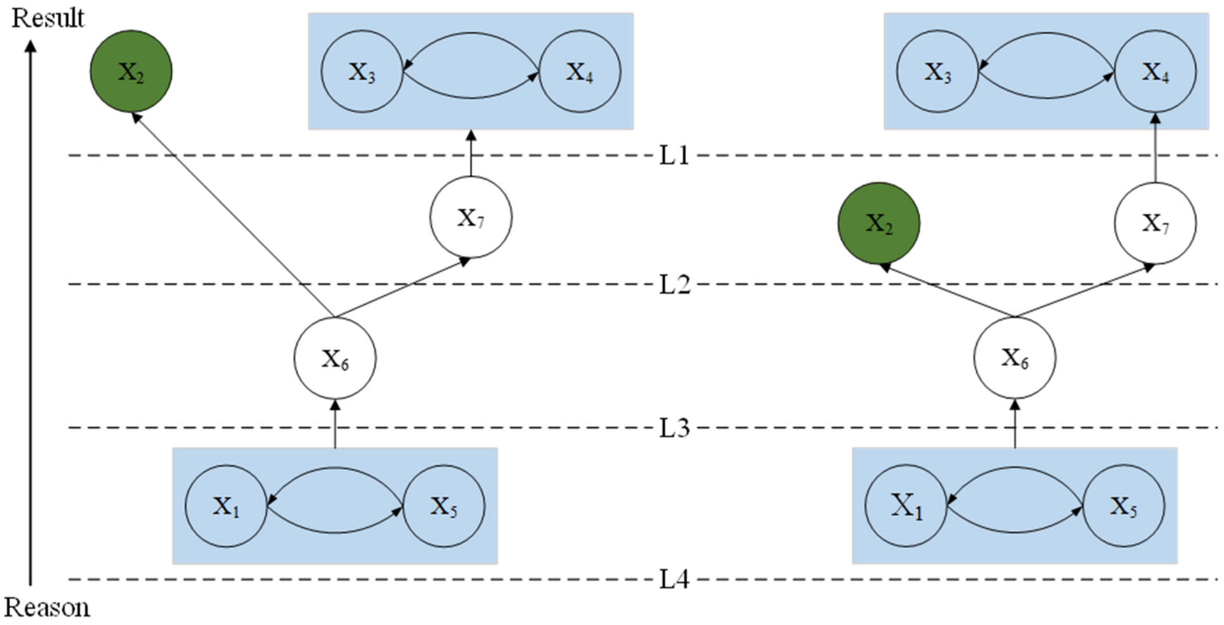

Figure 2. Topological hierarchy diagrams. UP-type hierarchical topology diagram (**left**) and DOWN-type hierarchical topology diagram (**right**) are drawn, reflecting the multi-level system of farmers' accepting CPD. X_1–X_7 are, respectively: agri-income, risk of pest, risk of health, risk of environment, cooperative, information acquisition, and government publicity.

4. Discussion

4.1. Analysis for Ecological Rational Decision-Making System of Accepting CPD

As a micro-behavior engaged in agri-production, the transformation of farmer's pesticide selection behavior is the key to ensuring food safety, controlling non-point source pollution and realizing sustainable development. Section 3 explores the multi-level determinants of farmers' adoption of CPD. A decision-making ecosystem for farmers' adoption of CPD was built based on ecological rationality at first. Then, the logistics-AISM model was used to verify the theoretical conjecture, and the independent role and hierarchical structure of each determinant in the system were analyzed.

4.1.1. The Whole Frame of CPD Decision-Making Ecosystem

According to Figure 2, the topological hierarchy diagrams showed a methodical decision-making ecosystem for accepting CPD by farmers from reason to result from bottom to top and divided the determinants into three levels.

Firstly, the union of the uppermost elements of the diagrams are the direct outcome factors, namely X_2 (Risk of pest), X_3 (Risk of health), and X_4 (Risk of environment). They directly affect farmers' adoption of CPD. Secondly, the intersection of the lowest-level elements of the diagrams are the root cause factors; that is, X_1 (Agri-income) and X_5 (Cooperative) are the deepest reasons for farmers to choose different pesticides. Finally, X_6 (Information acquisition) and X_7 (Government publicity) belong to the middle indirect factors, which connect the root factors and direct outcome factors together.

4.1.2. The Hierarchical Factor Analysis

(1) Direct outcome factors. Behavioral theory believes that cognition affects attitude, and attitude determines behavior. Our empirical results supported this view. Among the three significant cognitive ability variables, the regression coefficient of X_2 equals to -0.5383, and its sig. < 0.01, indicating that X_2 has a significant inhibitory effect on accepting CPD. For every unit increase in the risk of insect happened on crops, the probability of farmers rejecting the purchase of green pesticides in CPD will sharply increase by 58.37%. When farmers think that the risk of pests is particularly high, they tend to blindly use high-toxic pesticides to ensure crop safety, which is consistent with our theoretical expectations. Additionally, X_2 is an active element, which means it is at different levels in UP-type and DOWN-type, indicating that the decision-making ecosystem is active, which can be easily changed by external efforts.

The regression coefficients of X_3 and X_4 are 0.5204 and 0.7682, which promote farmers to accept CPD at the significant level of 10% and 1%, respectively, and validate the expectations before. That is, farmers are more likely to choose green pesticides from CPD if they think pesticides are more harmful to their own health and their living environment. Not only that, since the origins of farmer's cognition of X_3 and X_4 both come from the toxicity of pesticides, they influence each other and constitute a loop, which can be treated as a subsystem. Of course, as direct factors, X_2 and the loop of X_3-X_4 are affected by middle indirect environmental factors: X_6 and X_7.

(2) Middle indirect factors. X_7 with a regression coefficient of 3.4201 and sig. < 0.01 supposes that government publicity and its guidance have a significant positive impact on farmer's acceptance of CPD. Farmers who have once received government publicity are 3.4 times more willing to accepting CPD, compared with those who have not received it. This verified the effective role of publicity in CPD. To be specific, the government's efforts to promote CPD have directly affected farmers' awareness of the negative externalities of pesticides on human health and rural environment. Besides, due to the relatively high price of green pesticides and demanding technical requirements, farmers expect to receive government support in the production chain. The emergence of CPD caters the policy need of farmers. Therefore, official publicity makes farmers better understand the policy orientation, and thus makes them more willing to join CPD.

X_6, which has a regression coefficient of -0.4726, significantly affects X_2 and X_7 at a statistical level of 10%, suggesting that the easier it is for farmers to obtain agri-information, the more hesitant they will be to accept CPD. The possible explanation is that sufficient information is a mixed blessing. On the one hand, farmers can buy desirable pesticides easily, if they have access to adequate agri-information. It was found that a few well-informed farmers would go to agricultural material companies in other districts to purchase suitable pesticide at a cheaper price. On the other hand, according to the setting that farmers tend to like "effective information" rather than "full information" in the theory of farmers' ecological rationality, convenient ways to obtain agri-information are sometimes redundant and ineffective, which will cause non-optimal decisions by farmers' self-benefit. As the middle-level indirect factors influencing farmers' adoption of CPD behavior, X_6 and X_7 are affected by two deep-rooted factors, X_1 and X_5.

(3) Root factors. The regression coefficients of X_1 and X_5 are 2.5987 and 1.4142, and their statistical probabilities are 0.048 and 0.073, correspondingly, indicating that farmers with a large share of agri-income and members of cooperative society are more willing to accept CPD. This may be due to the behavior of obtaining higher income through the production of green agri-products is more profitable for households with a large proportion of agri-income. Consequently, they are more willing to adopt CPD.

Besides, farmers participating in the cooperative organization are more disposed to join CPD. Among the 62 cooperative households, 60 of them have purchased pesticides from the CPD (occupying 96.77%), noticeably higher than the corresponding ratio of not cooperative ones (81.87%). Cooperative society plays an important role in green agri-production. It offers not only high-price incentives but also strict supervision for the farmer. During field research, it is found that cooperatives often bid more for products with green pesticide and thus are of better quality, thereby stimulating farmers to join CPD. Cooperative also imposes constraints on members' agri-production to ensure food safety, and agri-products with excessive pesticide residues may face a worrying market. In addition, X_1 and X_5 also formed a subsystem; there is an interaction between the proportion of agri-income and whether to join a cooperative.

To sum up, the above seven determinants work individually and are also interrelated with each other, building a complete ecological rational decision-making system. As a root cause subsystem, X_1 and X_5 directly influence X_6 and then affect the choices of farmers along the two forward transmission paths. Path 1: "$X_6 \rightarrow X_2 \rightarrow$ behavior"; Path 2: "$X_6 \rightarrow X_3$ & $X_4 \rightarrow$ behavior". It can be clearly seen that the cognitive ability of farmers directly affects the behavior of accepting CPD; that is, changing farmers' pesticide purchase behavior must be based on correct cognition, which comes from two aspects: firstly, their own household business management (such as the proportion of agri-income), then the impact from external environments such as cooperatives and government.

4.1.3. The Insignificant Factors

Although the regression directions of age, education level, cadre experience, agri-laborer, farm size, soil fertility, and neighborhood are in line with expectation, local conditions lead them to the failure in the significance test in Logistic model. First of all, the surveyed area has obvious features such as aging, low level of education, and loss of young labors. A total of 81.12% of the interviewers are over 50 years old, and 80.69% have a junior high school education or below. Secondly, the local farm size is commonly small, with an average cultivated area of 0.55 ha, and the distance between farmlands is relatively close, resulting in little difference in soil fertility. Thirdly, field research found that farmers with cadre experience are mostly off-farmers and pay less attention to agriculture. The communication of agri-information among neighbors doesn't focus on pesticides.

Interestingly, the regression directions of risk of plant disease are contrary to expectation. Farmers believe that the greater the probability of plant disease, the more likely they are to adopt CPD, which is opposite to the regression result of pest. Through communication with local peasants, we found that they think the incidence of plant disease is lower than pest, and the damage of plant disease is slightly minor in surveyed area. Additionally, after reading the CPD sales list 2020, it was found that the 103 pesticides aim for disease (96 fungicides, 3 fungicides and acaricides, 4 regulators) in the list can be divided into 52 categories according to the effective ingredients. However, the 122 insecticides in the list can only be divided into 44 types according to the ingredients. In other word, the pesticides sold in CPD for curing diseases are more variety and cheaper than those for killing pest, which causes the coefficients of the two factors to be opposite.

4.2. Policy Implications

Our findings have some important policy implications for improving the current CPD policy, and providing lessons for other intensive farming countries to reduce the application of chemical pesticides, promote green pesticides, and control water pollution:

4.2.1. Improve CPD

As a unique local green agri-production policy, CPD has achieved remarkable success, but there are still areas for improvement. It can work better through the following implications:

- **More varieties and cheaper insecticides.** The negative effects of risk of pest on accepting CPD suggests that the government's efforts to improve CPD should focus on insecticides. When determining the pesticides sold in CPD system, more varieties of cheaper green insecticides should be included to provide more options for pest management, so as to encourage farmers to participate in CPD.
- **Increase publicity.** As a middle indirect factor that can change the cognition of farmers, the role of government publicity should not be underestimated. There seems to be a need to offer more knowledge about the CPD policy, agri-production safety and environment protection through TV, radio, media and village presentations. These appropriate external environmental interventions can influence farmers' cognitions, then affect their CPD acceptance behavior.

4.2.2. Lessons for Intensive Farming Countries

CPD offers an innovative flatform to guide farmers to use green pesticide, and its essence is to change their agri-production behaviors. Based on the verified logic of accepting CPD, the following lessons in promoting green pesticides are provided to China and other intensive farming countries.

- **More support for the sales of green agri-products.** Given that the proportion of agri-income is the root determinants that affects pesticide use, how to encourage farmers who make a living on agriculture to use more green pesticides is crucial. The government should ensure a stable and profitable sales channel of green agri-products and encourage these farmers to continue to use green pesticides. Then, establishing and improving the certification of green agri-products is also an incentive.
- **Play the auxiliary role of cooperatives.** Pay more attention to the positive incentives that cooperatives play in the pesticide selecting system. The cooperatives should play a role in motivating members to learn more agri-knowledge and organizing green agri-production, thus further motivating them to use green pesticides, promoting the process of agri-industrialization.
- **Develop eco-friendly pesticide.** At present, another reason hindering farmers from approving green pesticides is that the equation of "low toxicity = low efficiency" is deeply ingrained in farmers' hearts. Therefore, the research and development of low-toxic and high-efficiency eco-friendly pesticides cannot be delayed. The excellent prevention and control effects of green pesticides should be used to dispel the doubts in the minds of farmers, and help them to increase both efficiency and income.

4.3. Limitations

Our study advanced the previous literature on farmers' pesticide selection by analyzing a unique policy in Huangshan, China—Centralized Pesticide Delivery. Then, the Logistic-AISM model is introduced to examine the determinants of farmers' acceptance of CPD. By doing this, our study enriched microeconomics application of AISM and deepened the understanding of farmers' pesticide selection behavior.

However, this research has certain limitations. Due to the practical constraints, we only went to the representative Xiuning County to collect data. A comprehensive city-wide sample set cannot be provided there. Further studies in other counties, or other samples that carry out similar pesticide policies, should be investigated to test the validity of our findings.

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