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Does outsourcing pest control service adopted by farmers restrain their opportunistic behavior of disobeying specified pest control regulation in certified-vegetable planting areas?

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Ensuring the quality and safety of agricultural products and managing pesticide residues have become global issues, particularly in developing countries, small farmers' dynamic, the standardized use of pesticides, and the regulation of pest control behavior by small farmers remain a significant challenge. In China, the opportunistic behavior of farmers in certified vegetable areas who disobey specified pest control regulation, has led to issues such as frequent incidents of agricultural product quality and safety and prominent contradiction between the supply and demand of high-quality agricultural products. However, in recent years, the emergence of the outsourcing pest control service (OPCS) has provided a new idea for transforming pest control methods of smallholder farmers. This study based on survey data from certified vegetable areas of Shaanxi, Gansu, and Ningxia provinces in China, investigates the impact of outsourcing pest control services on the opportunistic behavior in pest control of farmers in certified-vegetable areas. The results of the study are as follows: First, the adoption of OPCS can significantly restrain the opportunistic behavior of farmers in certified vegetable areas. Second, the study found that when farmers purchase full-package services, the OPCS organization uses advanced pesticide equipment, and the service settlement opts for a fixed service price model, they are more likely to significantly reduce opportunistic behavior in pest control among certified farmers. Third, in the implementation of OPCS, factors such as farmers' providing pesticides, farmers' supervising OPCS operations, and signing a pest control service contract are associated with a stronger restraining effect on opportunistic behavior in pest control in certified vegetable areas. This study provides valuable insights for developing countries, particularly those with a "big country, small farmers" context, to promote the diffusion of outsourcing pest control services, the standardized use of pesticides, and the regulation of pest control behavior.

KEYWORDS

outsourcing pest control service, farmers, certified-vegetable planting areas, pest control, opportunistic behavior

1 Introduction

Pesticides, as indispensable inputs in modern agriculture, play a vital role in preventing and controlling crop pests and diseases and ensuring a stable supply of agricultural products. The scientific and rational use of pesticides to ensure the safety and stable supply of agricultural products is a critical issue for national well-being in every country worldwide. At present, many developing countries still face significant challenges in ensuring the safe use of pesticides and the regulation of pest control behavior. For example, according to statistics from the Food and Agriculture Organization of the United Nations (FAO), China ranks third globally in pesticide use, with its pesticide use far exceeding the world average by 2.5 times. Meanwhile, statistics from the Ministry of Agriculture and Rural Affairs of China (PRC) indicate that the pesticide utilization rate for major crops was 41% in 2023, with the intensity of pesticide application significantly exceeding the international safety threshold. Notably, the total pesticide residue exceedance rate for vegetables reaches 5.09% (Zeng and Qiao, 2023), significantly higher than that for other crops (Zhu and Li, 2018).

China is the world's largest vegetable producer, accounting for 55.17% of global production. Currently, four types of certified vegetables are produced in China: organic-certified, green-certified, qualified products, and geographical indication-certified vegetables. Different types of certified vegetables are subject to distinct pest control standards. In China's certified-vegetable production areas, farmers are primarily responsible for ensuring the quality and safety of vegetables. Why does the phenomenon of non-compliance with pesticide use standards still persist in certified-vegetable areas? Due to information asymmetry, inadequate quality control and traceability systems, an aging rural labor force, and small-scale, decentralized operations, whether small farmers, as rational economic agents, comply with pest control standards in certified-vegetable areas has largely become a "free choice" behavior (Chen, 2022). In pursuit of short-term profit maximization, farmers in certified-vegetable areas often engage in opportunistic behaviors, such as using banned pesticides, overapplying pesticides, and disobeying pesticide safety intervals (Jiang, 2020; Huang et al., 2021). These opportunistic behaviors have led to a series of issues, including frequent incidents of agricultural product quality and safety, agricultural non-point source pollution, and the prominent contradiction between the supply and demand of high-quality agricultural products (Garming and Waibel, 2009; Mahmood et al., 2016; Han et al., 2024). However, the Chinese government's "Central Document No. 1" of 2025 continues to emphasize strengthening the governance of agricultural product safety and deepening the management of pesticide residues. In this context, exploring how to constrain the opportunistic behavior of farmers in pest control in certified-vegetable areas has become a pressing and practical issue requiring urgent resolution in China.

In recent years, the emergence of the outsourcing pest control service (OPCS) has provided a new idea for transforming the pest control methods of smallholder farmers and achieving green pest control in certified-vegetable areas. OPCS refers to an efficient plant protection technology service in which farmers pay to outsource all or part of their crop pest control activities to professional service organizations for unified pest control (Wang et al., 2024). Current research on OPCS and pesticide application behavior has attracted considerable academic attention. Some studies suggest that OPCS can significantly reduce the intensity of pesticide use (Ying and Xu, 2017; Yan et al., 2024; Chang et al., 2024). From the perspective of pest control capability, compared with the decentralized, self-pest control model of smallholder farmers, OPCS organizations can judge the pest and disease situation promptly and apply pesticides scientifically, leveraging their professional expertise. This improves pest control effectiveness and consequently reduces the intensity of pesticide use (Sun et al., 2018; Yan et al., 2024). In terms of profit motivation, the paid nature of OPCS motivates OPCS organizations to consider costs and benefits when providing services, so the OPCS organizations spontaneously reduce the amount of pesticide inputs while ensuring the effectiveness of pest control (Fang et al., 2022; Han et al., 2024). However, some argue that OPCS may increase the intensity of pesticide use and exacerbate speculative behavior in pest control (Sun et al., 2018; Zheng and Zhang, 2022; Li et al., 2023). In terms of pest control effects, many non-professional OPCS providers, often merely hired laborers, still exist in the Chinese market. A substantial gap exists between their capabilities and those of professional OPCS organizations, potentially resulting in increased pesticide over-application (Zheng and Zhang, 2022; Li et al., 2023). From the perspective of profit motivation, on the one hand, farmers and OPCS organizations essentially exist within a "principal-agent" relationship characterized by conflicting interests and information asymmetry. In such cases, to gain more profits, the unethical OPCS organizations may "conspire" with the pesticide suppliers to apply excessive pesticides in the OPCS operations (Cai and Liu, 2019). On the other hand, as the profitability of most existing OPCS organizations is directly linked to operational volume, the unethical OPCS organizations may expedite pesticide equipment transfers between crops to increase the pest control service area. This often leads to insufficient or uneven spraying of pesticides, causing incomplete and recurring pest control problems, which in turn compel farmers to increase pesticide application frequency (Qing et al., 2023; An et al., 2024).

A review of the literature finds that current research remains controversial because it ignores the situational dependence of OPCS on pesticide application behavior. In other words, under different internal and external constraints (e.g., the service quality of OPCS, different service modalities provided by OPCS, whether farmers supervise OPCS operations, whether pesticides are supplied by farmers, and whether sign OPCS contracts between principal and agent parties), there may be differences in the impact of OPCS on pesticide application behavior. In addition, the current study only focuses on the impact of OPCS on pesticide application quantity, but there is a lack of research on whether pesticide use in OPCS operations complies with the pest control standards of certified-vegetable areas.

Overall, the study sought to answer the following research questions: (1) Does OPCS adopted by farmers restrain their opportunistic behavior of disobeying specified pest control regulation in certified-vegetable areas? (2) If so, how can the effective promotion of OPCS help reduce opportunistic behavior in pest control among farmers? (3) If not, how to strengthen the regulation of OPCS in certified areas and reduce opportunistic behavior in pest control in certified-vegetable areas? To address the above research questions, this study used the survey data from 644 farmers in certified vegetable areas in Shaanxi, Gansu, and Ningxia provinces in China to explore the impact of OPCS on the opportunistic behavior in pest control among farmers in vegetable certification areas. Additionally, the study further revealed the effect mechanisms of OPCS on the opportunistic behavior in pest control among farmers under different contextual dependencies. In contrast to the existing studies, this study provides three marginal contributions.

Firstly, existing research on OPCS and farmers' pesticide use behavior has mainly focused on wheat, rice, maize, or fruits, but research using vegetables as the research object is relatively scarce. According to statistics from the Ministry of Agriculture and Rural Affairs of China (PRC), the total pesticide residue exceedance rate for vegetables stands at 5.09%, significantly higher than that for other crops. Therefore, it is necessary to discuss the impact of OPCS on farmers' opportunistic behavior in pest control in vegetable certification areas.

Secondly, compared to traditional self-pest control by farmers, the OPCS organization offers significant advantages in pest observation and identification, pesticide selection, pest control time nodes, saving agricultural labor, and alleviating the aging of the planting workforce (Picazo-Tadeo and Reig-Martínez, 2006; Cai and Wang, 2021). Given the current situation in China, which is still dominated by small-scale farmers who engage in decentralized operations and self-pest control, and considering the realities of China's rural labor force, such as low education levels and an aging population, OPCS may be more aligned with the current and future development model of pest control in China. Thus, does OPCS adopted by farmers restrain their opportunistic behavior in pest control in certified vegetable areas? This study explored the answers to this focused question.

Finally, applying the "principal-agent" theory, this study incorporates factors such as the source of pesticide supply, farmers' supervision of the OPCS process, and the signing of OPCS service contracts into the "principal-agent" scenario to investigate whether the impact of OPCS on the opportunistic behavior of certified farmers in pest control differs across various "principal-agent" scenarios. This study offers a reference for decision-making aimed at improving the service level of OPCS, restraining the opportunistic behavior of farmers in certified-vegetable areas, and promoting the high-quality development of agriculture.

2 Concept definition and analysis of the theoretical mechanisms

2.1 Concept definition

2.1.1 Farmers' opportunistic behavior in pest control

Due to information asymmetry and unsound quality control-traceability mechanisms, farmers in certified vegetable production areas are still engaged in opportunistic behavior in pest control. Despite being aware of relevant certification standards, they pursue short-term profit maximization by using banned pesticides under certification standards, using pesticides in a single dose that exceeds the permitted amount for the corresponding type of certified vegetables, and failing to observe the safety intervals for pesticides specified for the corresponding type of certified vegetables.

2.1.2 Outsourcing pest control service

OPCS refers to an efficient plant protection technology service in which farmers pay to outsource all or part of their crop pest control activities to professional service organizations for unified pest control.

OPCS organizations provide integrated pest management services in two models: the semi-package service model and the full-package service model. The semi-package model refers to organizations that offer pest control services without providing pesticides, while the full-package model involves both pest control services and pesticide supply.

The technical support services provided by the OPCS organization are divided into two categories: traditional pesticide equipment and advanced pesticide equipment. Traditional pesticide equipment refers to backpack manual or electric sprayers powered by human labor, while advanced pesticide equipment includes self-propelled pesticide sprayers or plant protection UAV.

The service settlement methods for OPCS organizations are divided into two categories: settlement based on the service area and the single fixed service price. Settlement based on the service area refers to the method where OPCS organizations calculate the total service fees based on the actual land area for which they provide pest control services to the client, using the unit area price agreed upon in advance by both parties, and then charge accordingly after the service is completed. The single fixed service price refers to OPCS organizations charging a pre-agreed fixed total price for each service, with the price remaining constant regardless of actual pesticide usage, labor hours, or treatment area.

2.2 Analysis of the theoretical mechanisms

2.2.1 Effect mechanisms of OPCS on the opportunistic behavior of certified farmers in pest control

Pest control is a technology-intensive production process that requires pest controllers to possess a certain level of expertise and competence. However, in rural China, where information is relatively inaccessible, decentralized smallholder farmers are constrained in their pest control capacity by dual constraints in accessing information and adopting technology. This may result in limited pest control capacity among smallholder farmers, leading to opportunistic behaviors such as inadequate pest control, excessive pesticide application, and non-compliance with pesticide safety intervals. However, OPCS organizations, with their professional expertise in pest control, can judge the pest and disease situation promptly and use modern, efficient plant protection machinery and advanced application technology to apply pesticides scientifically. This could alleviate farmers' information constraints in pest control, thereby reducing opportunistic behavior resulting from their limited pest control capacity. In addition, OPCS organizations, utilizing their professional capacity, develop timely, green pest control programs and implement centralized pest control measures on vegetable plots that have purchased their services. This reduces pest control risks, thereby curbing opportunistic behaviors by decentralized smallholder farmers, such as excessive pesticide use or the application of banned pesticides in certified vegetable areas to avoid yield losses during severe pest outbreaks. Therefore, the adoption of OPCS can promote compliance with pest control standards among farmers in vegetable certification areas. Based on the above discussion, this study proposes the following hypotheses.

> *H1*: OPCS adopted by farmers restrains their opportunistic behavior of disobeying specified pest control regulation in certified-vegetable areas.

Different service modalities provided by OPCS organizations may have different effects on restraining the opportunistic behavior of farmers in pest control in certified vegetable areas. Specifically:

Firstly, in terms of the OPCS selection type offered by OPCS organisations. Compared to the half-package service model provided by OPCS organizations, the full-package service model grants has clearer pest control rights and responsibilities by entrusting all pest control work on farmers to OPCS organizations. To avoid being held accountable for poor results or excessive pesticide residues due to incomplete pest control, the OPCS organizations will be more cautious and scientific in controlling the pest control time nodes, pesticide selection, and pesticide application, to achieve the best control results. Based on the above discussion, this study proposes the following hypotheses.

> *H1-a*: Compared to the half-package service model, purchasing the full-package service model is more effective in restraining opportunistic behavior among farmers in pest control in certified-vegetable areas.

Secondly, in terms of the OPCS technical support offered by OPCS organisations. The use of advanced pesticide equipment (e.g., self-propelled pesticide sprayers or plant protection UAVs) by OPCS organizations improves spray targeting compared to traditional pesticide equipment, such as backpack manual or electric sprayers. This reduces pesticide drift losses and achieves precise pesticide application and large-scale pest control, offering advantages in saving pest control costs and enhancing pest control effects. Based on the above discussion, this study proposes the following hypotheses.

> *H1-b*: Compared to traditional pesticide equipment, the use of advanced pesticide equipment by OPCS organizations is more effective in restraining opportunistic behavior among farmers in pest control in certified-vegetable areas.

Thirdly, in terms of the OPCS settlement methods offered by OPCS organisations. Compared to settlement methods based on the outsourcing pest control service area, those based on a single fixed service price can avoid the profitability of the OPCS organizations being directly linked to the volume of work. Otherwise, OPCS organizations may be incentivized to increase the pest control service area by accelerating the movement of plant protection machinery between vegetable plots during pest control operations, leading to insufficient or uneven pesticide spraying. This results in incomplete pest control and recurring pests and diseases, thereby compelling farmers to increase the frequency of pesticide applications in contravention of pesticide safety intervals. Based on the above discussion, this study proposes the following hypotheses.

> *H1-c*: Compared to the settlement based on the service area, the settlement based on a single fixed service price is more effective in restraining opportunistic behavior among farmers in pest control in certified-vegetable areas.

In summary, there are differences in the effectiveness of OPCS selection types, technical support, and settlement methods in restraining the opportunistic behavior of farmers in pest control of certified-vegetable areas, among which the full-package service model, advanced pesticide equipment, and the settlement based on the single fixed service price are more likely to significantly reduce the opportunistic behavior and its degree in pest control among certified farmers.

2.2.2 The moderating role of farmers' providing pesticides, farmers supervising OPCS operations and signing OPCS contracts in the relationship between OPCS and opportunistic behavior among certified farmers in pest control

There may be differences in the impact of OPCS adoption on the opportunistic behavior among certified farmers in pest control under different "principal-agent" scenarios. Firstly, from the perspective of the sources of pesticide provision. If the pesticide is provided by OPCS organizations and service fees are linked to the amount of pesticide used, OPCS organizations may engage in opportunistic behavior during pest control operations in pursuit of higher profits, such as using a single dose of pesticide that exceeds the recommended amount indicated on the pesticide label or increasing the frequency of applications beyond the maximum safe-use limits. However, if pesticides are purchased and provided by farmers, the OPCS organization earns only service fees for pest control operations, this can fundamentally reduce the probability of opportunistic behavior in OPCS operations. Secondly, from the perspective of farmers supervising OPCS operations. If farmers supervise OPCS operations on site, it can effectively restrain and monitor the pest control behaviors of OPCS organizations. Additionally, farmers' supervision increases additional costs for OPCS organizations, such as refunds or free pesticide reapplications due to substandard OPCS operations, which further reduces opportunistic behaviors such as over-dispensing pesticides or increasing the number of pesticide applications due to incomplete pest control. Thirdly, in terms of signing OPCS contracts. Both the principal and the agent clarify their respective rights and responsibilities through the signing of pest control service contracts while using the terms of the contract to constrain the pest control behavior of the OPCS organization. This compels OPCS organizations to comply with the pest control standards in certified-vegetable areas, thereby reducing opportunistic behaviors in pest control in certified-vegetable areas. Based on the above discussion, this study proposes the following hypotheses.

> *H2*: The farmer providing pesticide, farmer supervising OPCS operation, and signing OPCS contract respectively play a positive moderator role in the process of OPCS inhibiting opportunistic behavior among farmers in pest control in certified-vegetable areas.

In summary, the logical framework for OPCS to restrain opportunistic behavior among farmers in pest control in certified vegetable areas is shown in Figure 1.

3 Materials and methods

3.1 Data sources

The data used in this study were obtained from a questionnaire survey conducted by the research group in June and July 2024 among

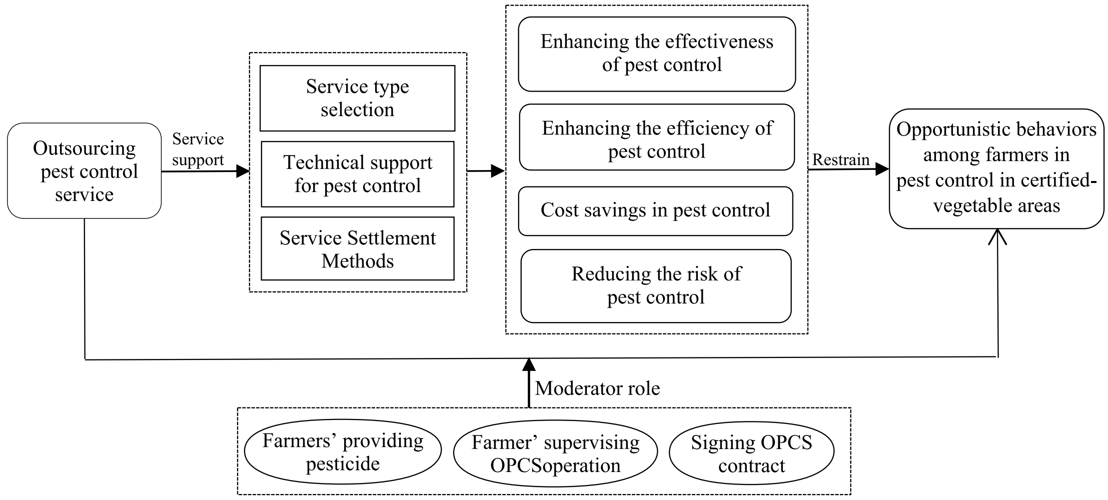

FIGURE 1
The logical framework of OPCS restrains the opportunistic behavior among farmers in pest control in certified-vegetable area.

growers of certified vegetable areas in Gansu, Shaanxi, and Ningxia provinces in China. The selection of the research area was based on the following considerations. Firstly, Shaanxi, Gansu, and Ningxia are representative advantageous production areas for vegetable cultivation in China's arid zones, characterized by extensive certified-vegetable areas and a diverse range of certified vegetable types. However, the pesticide residue exceedance rate of vegetables in the three provinces is higher than the national total pesticide residue exceedance rate of vegetables (Lu and Tian, 2022). Secondly, the results of the third batch of China's "Top 100 Counties for OPCS" in 2022 indicate that the development of OPCS in Northwest China is relatively underdeveloped, particularly in Shaanxi, Gansu, and Ningxia, where OPCS services for vegetables are obviously insufficient. Therefore, accelerating the development of OPCS in the arid zones of Northwest China has become an important and realistic issue that requires urgent resolution. Therefore, this study selects the farmers of certified vegetable areas in these three provinces as the survey subjects, which holds important research value.

In order to ensure the accuracy and scientificity of the questionnaire design, the research team looked for information on the vegetable cultivation area in Shaanxi, Gansu and Ningxia provinces, the types of vegetable certifications, the pest control standards for each type of certified vegetables (e.g., the list of banned pesticides for different types of certified vegetables, the pesticide dosage permitted for different types of certified vegetables for a single dosage, and the safety intervals for different types of certified vegetables, etc.) and the status of outsourcing pest control service for the design of the survey questionnaire. After the survey questionnaire design was completed, the research team invited six vegetable cultivation experts to check the survey questionnaire content and suggest modifications. After improving the questionnaire based on expert opinions, the research team selected 32 farmer households from two typical certified vegetable areas in Shaanxi Province for field pre-survey in January 2024. The survey questionnaire was revised and refined according to the pre-survey results, leading to the final version.

To ensure the scientific validity and representativeness of the survey data, we selected sample groups for investigation using a multi-stage process, taking into account objective factors such as vegetable planting areas in the three provinces, base certification types, unified prevention and the status of outsourcing pest control service, and regional differences. In the initial stage, the survey sample areas in the three provinces of Shaanxi, Gansu, and Ningxia in China were chosen based on the following three criteria: First, the scale of the survey areas in each province was determined according to the ratio of certified vegetable planting area in Gansu, Shaanxi, and Ningxia. Second, the specific survey areas selected in the three provinces belonged to the national "Green Pest Control Demonstration Counties," "Unified Prevention and Control Pilot Counties," or typical certified vegetable production bases in each province. Third, certified vegetable production was the main cash crop for local farmers, with income from certified vegetable planting accounting for more than 80% of households' total income. Based on these three criteria, 62 counties met the requirements for inclusion in the survey area. It uses systematic sampling. Firstly, according to the ratio of certified vegetable planting area in Gansu, Shaanxi, and Ningxia (1:0.78:0.31), a total of 5 cities were selected: 2 cities in Gansu (Tianshui and Lanzhou), 2 cities in Shaanxi (Baoji and Xianyang), and 1 city in Ningxia (Guyuan). Secondly, counties under the jurisdiction of 5 cities were selected from the 62 counties, and counties under the jurisdiction of 5 cities were ranked and re-screened according to the area of certified vegetable cultivation and types of certified vegetables. Finally, 6 counties were chosen: 3 counties in Gansu (Gangu, Wushan, and Yuzhong), 2 counties in Shaanxi (Jingyang and Taibai), and 1 county in Ningxia (Guyuan). During the second stage of sample group selection, sample size was determined as the number of secondary units (farmer) in the *i*th primary unit (county) by the following criteria:

$$n_{ij} = \left[\frac{u_\alpha v}{1-A}\right]^2 \tag{1}$$

In Equation 1, u_α represents a critical value that corresponds to a 95% confidence level; v represents the estimated coefficient of variation, which did not exceed 0.4; and A represents the range of estimated error, which did not exceed 10%. This determination yielded a minimum acceptable sample size of 62 secondary units (farmer) in each primary unit (county). When we increased the confidence level to 99%, the minimum number of secondary units (farmer) in each primary unit (county) was 106.

$$n=\left[\frac{1.96\times0.4}{0.1}\right]^2\approx62\quad n=\left[\frac{2.58\times0.4}{0.1}\right]^2\approx106$$

Assuming that 5% of the sample data will be missing, it determined a final sample size of 112 secondary units (farmer) in each primary unit (county), with a total sample size of 672. It used the combination of multi-stage sampling and random sampling in the field research. Two townships were randomly selected from each county, and two sample villages within certified vegetable area were randomly selected from each township. Then, 28 certified vegetable growers were randomly selected from each sample village in the certified vegetable production area, and one-on-one and face-to-face questionnaires were conducted. A total of 672 questionnaires were distributed in this survey. After removing questionnaires with missing or abnormal data, 644 valid questionnaires were obtained, yielding a response rate of 95.83%.

3.2 Descriptive statistics

First, descriptive statistics of the opportunistic behavior and its extent in pest control among sample farmers in certified-vegetable areas. Among the 644 sample farmers in the field study, 344 households (53.42%) used pesticides that are prohibited by the certification standards in their certified area (organic, green, conformity, and geographical indications). Two hundred and fifty households (38.82%) applied pesticide dosages exceeding the recommended single-use amount specified on the product label; 201 households (31.21%) did not comply with the safe use intervals during the pesticide application; 182 households (28.26%) applied pesticides more frequently than permitted under safe-use regulations; only 147 households (22.83%) complied with the pesticide use standards of certified-vegetable area. Further analysis revealed that 8.70% of farmers (56 households) exhibited all four types of opportunistic behaviors; 16.46% (106 households) and 15.99% (103 households) displayed 2 or 3 types, respectively; and 36.02% (232 households) exhibited one type. However, only 22.83% of farmers (147 households) demonstrated no opportunistic behavior in the pest control process. These findings indicate that the majority of farmers in certified-vegetable areas exhibit varying degrees of opportunistic behavior in the process of pest control (see Table 1).

Second, descriptive statistics on the farmers' choice of pest control methods in certified-vegetable areas. Among the total sample of farmers studied, 375 (58.23%) farmers opted for self-pest control, while 269 (41.77%) opted for OPCS to varying degrees. As shown in Table 2.

3.3 Variable selection

3.3.1 Dependent variables: opportunistic behavior in pest control

Based on the field survey, the opportunistic behavior of farmers' disobeying pest control regulation in certified-vegetable areas was measured in four aspects: (a) whether farmers used pesticides prohibited under certified-vegetable standards; (b) whether the single application dosage of pesticides exceeded the standard recommended dosage in pesticide specifications; (c) whether pesticide application did not comply with the safety interval; (d) whether the number of pesticide

TABLE 1 Descriptive statistics of the opportunistic behavior and its extent in pest control among sample farmers.

Opportunistic behavior of farmers' disobeying pest control regulation		Use of banned pesticides in certified-vegetable standards				Pesticide single dosage exceeds standard pesticide specifications				Failure to comply with safety intervals for pesticide applications				Number of pesticide applications exceeding safe use limits			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Province (region)	Shaanxi	4	22	0	80	4	19	1	68	3	17	0	61	2	13	3	59
	Gansu	10	8	9	131	10	8	12	82	3	7	8	72	11	10	10	59
	Ningxia	0	24	0	56	0	6	0	40	0	6	0	24	0	3	0	12
Total		14	54	9	267	14	33	13	190	6	30	8	157	13	26	13	130
Total (proportion)		344 (53.42%)				250 (38.82%)				201 (31.21%)				182 (28.26%)			

Degree of opportunistic behavior of farmers' disobeying pest control regulation		0	1	2	3	4	Total
Province (region)	Shaanxi	58	66	32	50	19	225
	Gansu	63	115	55	39	27	299
	Ningxia	26	51	19	14	10	120
Total		147	232	106	103	56	644
Total (proportion)		22.83%	36.02%	16.46%	15.99%	8.70%	100%

TABLE 2 Situations of sample farmer's selection of OPCS.

Full sample		Pest control methods		OPCS selection type		OPCS technical support		OPCS settlement method	
		Self-pest control of farmers	OPCS	Half-package service model	Full-package service model	Traditional pesticide equipment	Advanced pesticide equipment	Settlement based on the single fixed service price	Settlement based on the service area
Province	Shaanxi	131	110	147	94	157	84	168	73
	Gansu	187	116	197	106	194	109	196	107
	Ningxia	57	43	71	29	77	23	75	25

(a) Half-package service model means that OPCS organizations only provide pest control services but not pesticides, while the full-package service model means that OPCS organizations provide both pest control services and pesticides. (b) Traditional pesticide equipment refers to the use of manpower backpack manual or electric sprayers, while advanced pesticide equipment refers to the use of powered plant protection machinery such as self-propelled pesticide sprayers, or plant protection UAVs.

applications exceeded the prescribed safe-use limit. All the above 4 opportunistic behaviors are represented by 0 and 1. Farmers were classified as exhibiting opportunistic behaviors in pest control if they engaged in any one of the above behaviors. The degree of opportunistic behavior in pest control was measured by the total of the number types of opportunistic behavior choices made by farmers in pest control, which is an ordered discrete variable taking values of 0, 1, 2, 3, or 4.

3.3.2 Core independent variable: adoption of OPCS

In addition, in order to investigate whether the impact of OPCS adoption on the opportunistic behavior of certified farmers in pest control varies across different "principal-agent" scenarios, we also selected "OPCS selection type," "OPCS technical support" and "OPCS Settlement method" as additional explanatory variables to measure potential differences in effects.

3.3.3 Control variables

We selected 13 variables as control variables across the four dimensions. Firstly, we selected four control variables in terms of farmers' individual characteristics: age, education level, health status, and farmers' experience of pesticide poisoning. Secondly, we selected three control variables in terms of farm household characteristics: the number of the agricultural labor force, the number of migrant workers, and the ratio of agricultural income to total household income. Thirdly, we selected four control variables in terms of cultivation characteristics: certified-vegetable planting size, certified-vegetable planting years, severity of pests in vegetable plots, and degree of pesticide resistance. Fourthly, we selected 2 control variables in terms of external environmental characteristics: adoption of OPCS in neighboring plots and frequency of pesticide residue sampling.

3.3.4 Mechanism variables

In order to test the differences in the effectiveness of OPCS in suppressing opportunistic behavior of farmers in pest control of certified-vegetable areas under different "principal-agent" scenarios, we selected "farmer providing pesticide," "farmer supervising OPCS operation" and "signing OPCS contract" as the moderating variables.

3.3.5 Tool variable

We chose "Other farmers" evaluation of the OPCS effectiveness' as the tool variable.

The definitions, assignments, and descriptive statistics for each of the above categories of variables are shown in Table 3.

3.4 Econometric model

3.4.1 Endogenous switching regression model

Whether a farmer in a certified vegetable area adopts OPCS as their pest control method is the result of "self-selection." Moreover, there may be reverse causality between certified farmers' opportunistic behavior in pest control and their choice to adopt OPCS, leading to sample self-selection and endogeneity issues. In addition, it is not possible to simultaneously observe and evaluate a farmer's opportunistic behavior in pest control before and after the OPCS adoption.

Therefore, based on the framework of the "counterfactual," an endogenous switching regression model (ESR) was employed to empirically analyze the impact of OPCS on the opportunistic behavior and its degree among farmers in pest control in certified-vegetable areas. The model consists of two stages.

The first stage is the construction of a decision equation for the selection of OPCS by certified farmers:

$$D^* = \alpha S_i + k_i I_i + \mu_i \tag{2}$$

The second stage is the outcome equation. We constructed an influence effect equation of the choice of the OPCS on the opportunistic behavior and its degree among certified farmers in pest control:

$$Y_{Ti} = \beta_T + X_{Ti} + \varepsilon_{Ti} \; D = 1 \tag{3}$$

$$Y_{Ui} = \beta_U + X_{Ui} + \varepsilon_{ui} \; D = 0 \tag{4}$$

In Equations 2–4, D^* denotes the latent variable corresponding to the dummy variable D, which indicates whether a farmer adopts OPCS. S_i is the control variable that affects whether farmer i adopts OPCS. Y_{Ti} and Y_{Ui} denote the certified farmers' opportunistic behavior and its degree in pest control when they adopt OPCS or self-pest control, respectively. X_{Ti} and X_{Ui} are

TABLE 3 Definition of variables and descriptive statistics.

Variables	Definition and assignment	Mean	Std. dev.
Opportunistic behavior in pest control	Are there opportunistic behavior of farmers' disobeying pest control regulations in certified-vegetable areas (0 = no, 1 = yes)	0.722	0.420
The degree of opportunistic behavior in pest control	The total of the number types of opportunistic behavior choices made by farmers in pest control (0, 1, 2, 3, 4)	1.517	1.245
Adoption of OPCS	Whether farmers use outsourcing pest control service (OPCS) (0 = no, 1 = yes)	0.418	0.494
OPCS selection type	OPCS selection type chosen by the farmer (0 = half-package service model, 1 = full-package service model)	0.356	0.479
OPCS technical support	What is the pesticide equipment used by OPCS organization for pest control operations for farmers [0 = traditional pesticide equipment (such as manpower backpack manual or electric sprayers), 1 = advanced pesticide equipment (such as self-propelled pesticide sprayers or plant protection UAV)]	0.335	0.472
OPCS settlement method	What is the method of settlement for the OPCS purchased by farmers (0 = based on service area, 1 = based on single fixed service price)	0.318	0.466
Age	Age of household production and operation decision makers (years)	54.339	9.058
Education level	Education of household production and operation decision makers (1 = no education, 2 = primary school, 3 = junior high school, 4 = high school or secondary school, 5 = college and above)	2.807	1.132
Health status	Health status of household production and operation decision makers (1 = very poor, 2 = poor, 3 = fair, 4 = better, 5 = very good)	3.418	1.273
Farmers' experience of pesticide poisoning	Have the household production and operation decision makers experienced pesticide poisoning in pest control in the last 3 years (0 = no, 1 = yes)	0.489	0.500
Number of the agricultural labor force	Total family agricultural labor force (persons)	2.441	1.145
Number of migrant workers	Number of family workers outside the home (persons)	0.879	0.949
The ratio of agricultural income to total household income	Income from agricultural production /total household income (%)	0.612	0.329
Certified-vegetable planting size	Your household's certified-vegetable acreage (acres)	6.127	6.613
Certified-vegetable planting years	Certified-vegetable planting years of household production and operation decision makers (years)	21.211	11.267
Severity of pests in vegetable plots	What is the degree of pests in your vegetable field (1 = almost none, 2 = a little, 3 = average, 4 = more severe, 5 = very severe)	3.394	1.197
Degree of pesticide resistance	Degree of pesticide resistance in farmers' certified-vegetable plots (1 = basically none; 2 = mild; 3 = average; 4 = severe; 5 = very severe)	2.657	1.343
Adoption of OPCS in neighboring plots	Are the neighboring certified-vegetable plots of the farmers adopting the OPCS (0 = no, 1 = yes)	0.320	0.467
Frequency of pesticide residue sampling	How many times did the government department conduct total pesticide residue sampling tests on certified vegetables at your area last year (times/year)	1.640	2.900
Farmer' providing pesticide	Are pesticides provided in OPCS operation by the farmers themselves (0 = no, 1 = yes)	0.242	0.429
Farmer' supervising OPCS operation	Do farmers provide on-site supervision of OPCS operation (0 = no, 1 = yes)	0.244	0.430
Signing OPCS contract	Whether farmers adopting OPCS have signed service contracts with the OPCS organization (0 = no, 1 = yes)	0.259	0.439
Other farmers' evaluation of the OPCS effectiveness	How do other farmers in this village evaluate the OPCS effectiveness (1 = very dissatisfied; 2 = quite dissatisfied; 3 = average; 4 = quite satisfied; 5 = very satisfied)	2.776	1.376

covariates that may affect farmers' choices of OPCS and self-pest control, respectively. α, β_T, and β_U are coefficients to be estimated. u_i, ε_{Ti}, and ε_{Ui} are random error terms. In the ESR model, a tool variable I_i that is excluded from X_i must be included in S_i to address the endogeneity issue. At the same time, the tool variable selection should directly affect the adoption decision of OPCS by certified farmers but not directly influence the opportunistic behavior and its degree among certified farmers in pest control. Therefore, we selected "Other farmers" evaluation of the effectiveness of OPCS' as the tool variable.

To further control for the biased estimation caused by unobservable factors that simultaneously influence both certified farmers' opportunistic behavior in pest control and their decision to adopt OPCS, the inverse Mills ratio computed from Equation 1 was incorporated into Equations 3, 4. Thus, we obtain:

$$Y_{Ti} = \beta_T + X_{Ti} + \sigma_{T\mu}\lambda_{Ti} + \varepsilon_{Ti} \;\; D = 1 \tag{5}$$

$$Y_{Ui} = \beta_U + X_{Ui} + \sigma_{U\mu}\lambda_{Uu} + \varepsilon_{ui} \;\; D = 0 \tag{6}$$

In Equations 5, 6, λ_{Ti} and λ_{Ui} represent the unobservable variables that generate selection bias. σ_{Tu} and σ_{Uu} denote the covariances between the error terms of the selection equations and outcome equations, respectively.

3.4.2 Estimation of treatment effects based on endogenous switching regression model

Based on Equations 5, 6, we denote the conditional expectation of certified farmers' opportunistic behavior in pest control under OPCS adoption or self-pest control, respectively, as follows:

$$E\left[Y_{Tt} \middle| D = 1\right] = \beta_T X_{Ti} + \sigma_{T\mu}\lambda_{Ti} \tag{7}$$

$$E\left[Y_{Ui} \middle| D = 0\right] = \beta_U X_{Ui} + \sigma_{U\mu}\lambda_{Uu} \tag{8}$$

Under the counterfactual hypothesis, the conditional expectation of opportunistic behavior in pest control for certified farmers who adopt OPCS, had they instead chosen self-pest control, is expressed as follows: Similarly, the conditional expectation of opportunistic behavior in pest control for certified farmers who choose self-pest control, had they instead adopted OPCS, is expressed as follows:

$$E\left[Y_{Ui} \middle| D = 1\right] = \beta_U X_{Ti} + \sigma_{Uu}\lambda_{Ti} \tag{9}$$

$$E\left[Y_{Ti} \middle| D = 0\right] = \beta_T X_{Ui} + \sigma_{Tu}\lambda_{Uu} \tag{10}$$

The average treatment effect (ATT) of opportunistic behavior in pest control for farmers (treatment group) choosing OPCS is the difference between Equations 7 and 9. It can thus be expressed as Equation 11:

$$\text{ATT} = E\left[Y_{Ti} \middle| D = 1\right] - E\left[Y_{Ui} \middle| D = 1\right] = \left(\beta_T - \beta_U\right) X_{Ti} + \lambda_{Ti}\left(\sigma_{Y\mu} - \sigma_{U\mu}\right) \tag{11}$$

The average treatment effect (ATT) of opportunistic behavior in pest control for farmers (control group) choosing self-pest control is the difference between Equations 8 and 10. It can thus be expressed as Equation 12:

$$\text{ATU} = E\left[Y_{Ti} \middle| D = 0\right] - E\left[Y_{Ui} \middle| D = 0\right] = \left(\beta_T - \beta_U\right) X_{Ui} + \lambda_{Ui}\left(\sigma_{T\mu} - \sigma_{U\mu}\right) \tag{12}$$

4 Empirical results

4.1 Effect of OPCS on the opportunistic behavior of certified farmers in pest control

The results of the joint estimation of the decision-making model for OPCS adoption by certified farmers and the model for opportunistic behavior in pest control are presented in Table 4. The likelihood ratio test (LR) indicates that the selection and outcome equations were significantly and positively correlated at the 1% level. Furthermore, the correlation coefficients ρ_0 and ρ_1 were both statistically significant at the 1% level. These results suggest that the sample has a self-selection problem due to unobservable factors, thereby validating the necessity of employing an endogenous switching regression model.

4.1.1 Analysis of the results of the estimation of the decision-making model for the adoption of OPCS by certified farmers

The estimation results of the selection equation presented in column (1) of Table 4 indicate the following: Firstly, the health status of the household's production and operation decision-maker and the number of agricultural laborers in the household have significant negative effects on OPCS adoption decisions of certified farmers at the 10 and 5% levels, respectively. In contrast, the number of migrant workers in the household has a significant positive effect on OPCS adoption of certified farmers at the 5% level. The results of this study are consistent with the conclusions of Chen et al. (2024). This may be attributed to the fact that pest control is a technology-intensive process requiring considerable inputs of labor, materials, and time. When the household decision-maker is in poor health, agricultural labor is scarce, or the number of migrant workers is high, a shortage of personnel for pest control arises, thereby increasing the likelihood of adopting OPCS to compensate for the labor deficit. Secondly, farmers' experience of pesticide poisoning has a significant positive effect on the OPCS adoption decisions of certified farmers at the 5% level. This is likely because farmers who have experienced pesticide poisoning gain a deeper understanding of its health risks and become more concerned about their safety and health. This heightened awareness encourages them to adopt OPCS as a means of reducing direct exposure to pesticides and thereby minimizing the risk of poisoning. These findings are consistent with the conclusions of Sun and Xing (2022) and Sun et al. (2018) that the frequency of pesticide residue testing promotes farmers' adoption of outsourcing pest management services. Finally, certified-vegetable planting size, severity of pests in vegetable plots, degree of pesticide resistance, adoption of OPCS in neighboring plots, frequency of pesticide residue sampling, and other farmers' evaluation of OPCS effectiveness all significantly and positively influenced the OPCS adoption decisions of certified farmers at the 1% level. This is consistent with the findings of Zheng and Zhang (2022) and Chen et al. (2024). A possible explanation is that larger certified-vegetable planting sizes are often associated with more frequent pest outbreaks. In such cases, farmers may face inadequate pest control or miss the optimal timing for intervention due to limited personal capacity or labor shortages, resulting in greater yield losses in vegetable production. OPCS organizations have professional pest control teams that are more proficient in the pest control time nodes, pesticide selection, application, etc. This enables

TABLE 4 Joint estimation results of endogenous switching regression model.

Variables	Selection equation	Outcome equation			
	OPCS adoption decisions (1)	Opportunistic behavior (2)		Degree of opportunistic behavior (3)	
		Self-pest control of farmers	OPCS	Self-pest control of farmers	OPCS
Age	−0.004 (0.008)	0.002 (0.002)	0.002 (0.003)	0.002 (0.005)	0.006 (0.005)
Education	0.090 (0.063)	−0.025** (0.012)	−0.049** (0.024)	−0.077** (0.035)	−0.184** (0.041)
Health status	−0.111* (0.059)	−0.010 (0.011)	−0.015 (0.024)	−0.025 (0.035)	−0.058 (0.041)
Farmers' experience of pesticide poisoning	0.300** (0.141)	−0.083*** (0.031)	−0.019 (0.050)	−0.711*** (0.095)	−0.070 (0.083)
Number of the agricultural labor force	−0.152** (0.060)	−0.039*** (0.013)	−0.084*** (0.021)	−0.152*** (0.039)	−0.217*** (0.037)
Number of migrant workers	0.153** (0.068)	0.071*** (0.150)	0.129*** (0.024)	0.203*** (0.046)	0.164*** (0.040)
Ratio of agricultural income to total household income	0.221 (0.218)	−0.217*** (0.042)	−0.295*** (0.077)	−0.340*** (0.129)	−0.378*** (0.132)
Certified-vegetable planting size	0.046*** (0.014)	−0.020*** (0.004)	−0.009*** (0.003)	−0.036*** (0.012)	−0.013*** (0.005)
Certified-vegetable planting years	−0.004 (0.006)	−0.001 (0.001)	−0.003 (0.002)	−0.019*** (0.004)	−0.002 (0.004)
Severity of pests in vegetable plots	0.156*** (0.059)	0.030*** (0.010)	0.095*** (0.021)	0.059*** (0.010)	0.183*** (0.036)
Degree of pest resistance	0.158*** (0.056)	0.042*** (0.012)	0.097*** (0.020)	0.226*** (0.036)	0.094*** (0.035)
Adoption of OPCS in neighboring plots	0.944*** (0.156)	−0.094 (0.148)	−0.216 (0.165)	−0.159 (0.152)	−0.127 (0.102)
Frequency of pesticide residue sampling	0.107*** (0.041)	−0.042*** (0.012)	−0.018*** (0.006)	−0.012*** (0.003)	−0.033*** (0.010)
Other farmers' evaluation of the OPCS effectiveness	0.461*** (0.056)	—	—	—	—
ρ_0	—	0.125*** (0.037)	—	0.322*** (0.071)	—
ρ_1	—	—	−0.700***(0.124)	—	−0.239*** (0.056)
LR statistic	12.05***	—		—	
Log likelihood	−334.57***	—		—	

① *, **, and *** indicate significance at the 10, 5, and 1% levels, respectively. ② Standard errors are in parentheses. ③ Same as below.

precise pesticide application and expands the scale of pest control, thereby reducing costs and enhancing both the effectiveness and efficiency of pest control. In addition, when pest infestations are severe and pesticide resistance is high in vegetable areas, farmers often resort to nonstandard and hasty pest control methods to quickly control yield losses. This behavior may further exacerbate pest severity and pesticide resistance. However, OPCS organizations, leveraging their professional expertise, can accurately diagnose pest conditions promptly and apply pesticides timely and appropriately using efficient pesticide equipment and advanced pesticide application techniques. This approach significantly reduces pest severity and pesticide resistance, thereby reducing pest control risks and improving pest control effectiveness. Therefore, the greater the certified-vegetable planting scale, the more severe the pest issues, and the stronger the resistance, the more likely farmers are to adopt OPCS. In addition, under the influence of the "acquaintance society" in rural China, farmers' choices of pest control methods are heavily influenced by surrounding peers. If neighboring plots adopt OPCS and the results are perceived as effective, farmers tend to imitate this approach voluntarily for economic benefit. Thus, both the adoption of OPCS by neighboring plots and positive evaluations from fellow farmers promote broader OPCS adoption. Regulatory inspections for pesticide residues by agricultural authorities raise the cost of non-compliance, thereby compelling farmers to adopt OPCS to improve pest control effectiveness. The adoption of OPCS reduces both pesticide usage and application repetition, thereby reducing the risk of pesticide residues exceeding the standard.

4.1.2 Analysis of the results of the estimation of opportunistic behavior of certified farmers in pest control

The estimation results of the outcome equations in columns (2) to (3) of Table 4 reveal that the factors influencing both the opportunistic behavior and its degree of pest control differ significantly between the two groups of certified farmers who opt for self-pest control and those who adopt OPCS. A more detailed examination of these distinctions is provided below.

Firstly, concerning farmers' individual characteristics, the education level of household production and operation decision-maker was found to significantly and negatively influence both the opportunistic behavior and its degree in pest control across both groups of certified farmers at the 5% level. Meanwhile, farmers' past experience of pesticide poisoning had a significant negative effect only among those who engaged in self-pest control, at the 1% level. This likely reflects that farmers with higher levels of education tend to exhibit greater caution in the purchase, proportion, and application of pesticides. Moreover, since farmers adopting OPCS, are not directly exposed to pesticides, their experience of pesticide poisoning only affects the opportunistic behavior and its degree in pest control among self-pest control of farmers. The experience of pesticide poisoning makes farmers who manage pest control themselves become fearful and careful towards pesticides, motivating them to select safe and less toxic pesticides and to correct irregular pest control behavior to avoid further pesticide poisoning again. This behavior ultimately reduces both the opportunistic behavior and its degree in pest control among self-pest control farmers.

Secondly, in terms of household characteristics, both the number of agricultural laborers in the household and the ratio of agricultural income to total household income significantly and negatively affected opportunistic behavior and its degree in pest control among both groups of certified farmers, at the 1% level. Conversely, the number of migrant workers significantly and positively affected such behavior, also at the 1% level. This suggests that the adoption of green pest control technologies requires more labor and time costs due to the need for higher labor, new technology and equipment, and practical operation requirements. Households with more available agricultural labor or fewer migrant workers tend to have a sufficient labor supply for pest control, increasing the likelihood of adopting green prevention and control technologies, thereby reducing the frequency of pesticide application. Furthermore, a higher proportion of agricultural income in total household income implies a greater dependence on agricultural production, which incentivizes farmers to comply with pesticide use standards in vegetable certification areas to avoid production risks and to obtain stable income.

Thirdly, regarding cultivation characteristics, certified-vegetable planting size significantly and negatively affects opportunistic behavior and its degree in pest control for both groups of certified farmers at the 1% level. This may be attributed to the fact that the larger the certified vegetable cultivation size, the greater the farmers' awareness of risk prevention and the need to maintain their market reputation. Consequently, farmers with larger certified-vegetable plots tend to make more prudent decisions in purchasing and applying pesticides and are more inclined to adopt scientific and standardized green pest control measures to ensure the quality and safety of vegetables. This behavior ultimately contributes to reducing both the opportunistic behaviors and their extent. In contrast, both the severity of pests in vegetable plots and the degree of pest resistance significantly and positively influenced the opportunistic behavior and its degree of pest control at the 1% level for both groups of farmers. The reason is that when pest resistance is high and outbreaks are severe, unethical farmers or OPCS organizations may resort to the overuse of pesticides, the use of prohibited pesticides under the certified-vegetables standard, or other hasty means of pest control to mitigate yield losses rapidly. Severe pest pressure has weakened the operational awareness of certified farmers to regulate pest control, thereby exacerbating opportunistic behavior and its degree of pest control in certified vegetable areas.

Fourthly, in terms of external environmental characteristics, the frequency of pesticide residue sampling significantly and negatively affects both opportunistic behavior and its degree of pest control among both groups of certified farmers at the 1% level. A plausible explanation is that pesticide residue sampling of vegetables by agricultural regulatory authorities elevates the potential cost of non-compliance with pesticide regulations. This heightened risk acts as a deterrent, compelling farmers or OPCS organizations to adhere more strictly to pesticide use standards mandated by vegetable-certification requirements, thereby reducing opportunistic behavior and its degree in pest control in certified vegetable areas.

4.1.3 Average treatment effect

4.1.3.1 Average treatment effect of OPCS on the opportunistic behavior of certified farmers in pest control

Table 5 reports the estimation results of average treatment effects (ATT and ATU) of OPCS adoption on the opportunistic behavior of certified farmers in pest control under the framework of the "counterfactual." As shown in Table 5, OPCS significantly reduced both the incidence and severity of opportunistic behavior in pest control among certified farmers. Specifically, under the counterfactual hypothesis, certified farmers who actually adopted OPCS would exhibit an increase in opportunistic behavior from 0.606 to 0.743 (an increase of 22.61%) and an increase in the degree of opportunistic behavior from 1.296 to 1.781 (an increase of 37.42%), if they had instead chosen self-pest control. Similarly, certified farmers who actually chose self-pest control would reduce their opportunistic behavior and its degree by 28.61 and 11.82%, respectively, if they had adopted OPCS. Taken together, these results suggest that OPCS adopted by farmers restrains their opportunistic behavior in pest control in certified-vegetable areas, thus supporting hypothesis H1. An et al. (2024) found that farmers who outsourced pesticide application services sprayed 0.4 times less on average than farmers who applied pesticides themselves. This is similar to the results of this study.

4.1.3.2 Average treatment effect of different service modalities provided by OPCS in influencing opportunistic behavior of certified farmers in pest control

Table 6 reports the differences in the effectiveness of different service modalities provided by OPCS in restraining opportunistic behavior and its degree in pest control among certified farmers (ATT). Specifically, the results are as follows:

Firstly, in terms of the OPCS selection type, compared to the half-package service model provided by OPCS organizations, the full-package service model is more effective in significantly reducing both

TABLE 5 Average treatment effect of OPCS on the opportunistic behavior of certified farmers in pest control.

Farmers' group	Opportunistic behavior					Degree of opportunistic behavior				
	OPCS	Self-pest control	ATT	ATU	Rate of change	OPCS	Self-pest control	ATT	ATU	Rate of change
Certified farmers adopting OPCS	0.606	0.743	−0.137***	—	22.61%	1.296	1.781	−0.485***	—	37.42%
Certified farmers adopting self-pest control	0.891	1.248	—	−0.357***	28.61%	1.731	1.963	—	−0.232***	11.82%

opportunistic behavior and its degree in pest control among certified farmers. Specifically, under the counterfactual hypothesis, certified farmers who actually utilize the half-package service model would reduce their opportunistic behavior and its degree in pest control by 29.30 and 68.34%, respectively, if they opted for the full-package service model. These findings confirm hypothesis H1-a. The results of this study are consistent with the findings of Chen and Zhou (2022), which concluded that farmers who chose the full-package service achieved more significant reductions in pesticide use than those who chose the half-package service or the self-pest control.

Secondly, in terms of the OPCS technical support, if OPCS organizations that currently use traditional pesticide equipment switch to advanced pesticide equipment (e.g., self-propelled pesticide sprayers or plant protection UAVs) for pest control operations, the opportunistic behavior and its degree among certified farmers in pest control would decrease by 22.77 and 57.32%, respectively. These findings support hypothesis H1-b. This is similar to the research findings of Huang et al. (2021) and Li et al. (2023).

Thirdly, from the perspective of the OPCS settlement methods, compared to the settlement based on the service area, the settlement based on a single fixed service price would reduce opportunistic behavior and its degree in pest control among certified farmers by 31.96 and 79.41%, respectively.

In summary, different service modes provided by OPCS organizations have different restraining effects on the opportunistic behavior and its degree in pest control among certified farmers, among which the full-package service model, the use of advanced pesticide equipment, and the settlement method based on a single fixed service price are more effective in significantly reducing the opportunistic behavior and its degree in pest control among certified farmers.

4.2 Robustness test

To test the robustness of the previous estimation results, this study employs the propensity score matching method (PSM). In this study, the samples from the treatment group (certified farmers adopting by OPCS) and the control group (certified farmers adopting by self-pest control) were matched. Subsequently, a common support domain test and a balance test were conducted to evaluate the quality of the matched data. After the completion of the test, the average treatment effect (ATT) of OPCS and its different service modalities on opportunistic behavior and its degree among certified farmers in pest control was measured using four matching methods: nearest neighbor matching ($k = 4$), caliper matching (caliper width = 0.01), radius matching, and kernel matching (using the default kernel function and bandwidth).

As shown in Table 7, the results across the four matching methods are relatively close, and the ATT estimates are all significant at the 1% level. The mean ATT values for the opportunistic behavior and its degree among certified farmers in pest control were 0.204 and 0.397, respectively. This indicates that certified farmers who opted for OPCS exhibited 20.38 and 37.90% less opportunistic behavior and its degree in pest control, respectively, compared to those who adopted self-pest control. These findings indicate that OPCS does restrain opportunistic behavior among certified farmers in pest control, which is broadly consistent with the previous estimation results. Thus, the estimation results of the endogenous switching model are robust, and hypothesis H1 is again confirmed.

As shown in Table 8, the average treatment effects (ATT) for OPCS selection type, OPCS technical support, and OPCS settlement method are all significant at the 1% level. The ATT results are evident. Firstly, in terms of the OPCS selection type, certified farmers who opted for the full-package service model exhibited 27.45 and 57.58% reduced opportunistic behavior and its degree among certified farmers in pest control, respectively, compared to those who chose the half-package service model. Secondly, in terms of the OPCS technical support, the use of advanced pesticide equipment by OPCS organizations reduced opportunistic behavior and its degree among certified farmers in pest control by 22.50 and 52.23%, respectively, compared to the use of traditional pesticide equipment. Thirdly, from the perspective of the OPCS settlement methods, compared to the settlement based on the outsourcing pest control service area by OPCS organizations, the settlement based on a single fixed service price would reduce opportunistic behavior and its degree among certified farmers in pest control by 34.98 and 74.90%, respectively. These results show that the estimates obtained from the PSM model differ only slightly from the previous endogenous switching regression model (ESR) estimates, suggesting that the ESR model results are robust. Thus, hypotheses H1-a, H1-b, and H1-c are again confirmed.

TABLE 6 Average treatment effect of different service modalities provided by the OPCS organization on the opportunistic behavior of certified farmers in pest control.

Variable	OPCS selection type				OPCS technical support				OPCS settlement method			
	Full-package service model	Half-package service model	ATT	Rate of change	Advanced pesticide equipment	Traditional pesticide equipment	ATT	Rate of change	Settlement based on the single fixed service price	Settlement based on the service area	ATT	Rate of change
Opportunistic behavior	0.546	0.706	−0.160***	29.30%	0.571	0.701	−0.130***	22.77%	0.535	0.706	−0.171***	31.96%
Degree of opportunistic behavior	0.916	1.542	−0.626***	68.34%	0.949	1.493	−0.544***	57.32%	0.850	1.525	−0.675***	79.41%

4.3 Endogeneity test

In the previous analysis, although the endogenous switching regression model (ESR) has addressed the issues of sample selection bias and endogeneity caused by reverse causality, unobservable omitted variables may still lead to endogeneity problems. Therefore, drawing on the research of An et al. (2024) and Chen et al. (2024), we select the "Proportion of villages adopting OPCS" as an instrumental variable and further employ the instrumental variable method to eliminate endogeneity issues in the econometric model.

According to social interaction theory, farmers' behavioral decisions are influenced not only by their own capabilities, preferences, and resource endowments but also inevitably by others (Manski, 2000). Rural China is a typical "differential sequence pattern" relational society, where behavioral patterns among farmers in a village exhibit "demonstration effects" and "neighborhood effects." The higher the adoption rate of unified OPCS in a village, the greater the likelihood that farmers will choose such services under the influence of rural social networks, driven by a herd mentality. In other words, a high adoption rate of unified OPCS may reduce individual farmers' information search costs and perceived risks, increase their trust in such services, and directly influence the probability of other farmers in the village choosing OPCS. However, the village-level adoption rate of unified OPCS does not directly influence individual farmers' specific pest control behaviors in their own vegetable plots. Therefore, the "Proportion of villages adopting OPCS" meets the dual criteria of "relevance and exogeneity" for instrumental variables, effectively mitigating endogeneity issues.

This study employed the IV-probit model and the IV ordered probit model to conduct endogeneity tests. The test results are shown in Table 9. The results of the first-stage regression indicate that the proportion of villages adopting OPCS' significantly and positively influences the "Adoption of OPCS" at the 1% level, with an *F*-value exceeding 10. This indicates that there is no problem with a weak instrumental variable. The results of the second stage regression of the IV-probit model (with opportunistic behavior in pest control as the dependent variable) and the IV ordered probit model (with degree of opportunistic behavior in pest control as the dependent variable) showed that both the signs of the coefficients for "Adoption of OPCS" and their significance level of were consistent with those of the baseline regression. This implies that after addressing the endogeneity issue through the instrumental variable method, "Adoption of OPCS" still exerts a statistically significant negative impact on farmers' opportunistic behavior and its degree in pest control, further validating hypothesis H1.

4.4 Moderating effect tests

Table 10 reports the differences in the impact of OPCS on opportunistic behavior and its degree among farmers in pest control in certified-vegetable areas based on different "principal-agent" scenarios.

Firstly, in terms of the sources of pesticide provision, the interaction term "Adoption of OPCS" × Farmers' providing pesticides' all significantly and negatively affected the opportunistic behavior and its degree among certified farmers in pest control at the 10% level. This suggests that when pesticides are provided by farmers themselves

TABLE 7 Average treatment effect of OPCS on the opportunistic behavior among certified farmers in pest control.

Matching mode	Opportunistic behavior			Degree of opportunistic behavior		
	Certified farmers by OPCS	Certified farmers by self-pest control	ATT	Certified farmers by OPCS	Certified farmers by self-pest control	ATT
Nearest neighbor matching	0.642	0.856	−0.214***	0.974	1.403	−0.429***
Caliper matching	0.642	0.856	−0.214***	1.059	1.426	−0.367***
Radius matching	0.674	0.852	−0.178***	1.060	1.434	−0.374***
Kernel matching	0.642	0.851	−0.209***	0.974	1.320	−0.346***
Average value after matching	0.650	0.854	−0.204***	1.017	1.396	−0.379***

during OPCS operations, the inhibitory effect on the opportunistic behavior in pest control in certified-vegetable areas is stronger.

Secondly, in terms of the supervision of OPCS operations, the interaction term "Adoption of OPCS" × Farmers' supervising OPCS operations' is significantly negative at the 1% level. This suggests that farmers' supervising OPCS operations positively moderates the effect of OPCS in restraining opportunistic behavior and its degree among certified farmers in pest control. In other words, the suppression of opportunistic behavior among certified farmers in pest control is stronger when certified farmers participate in supervising OPCS operations.

Thirdly, in terms of the signing of OPCS contracts, the interaction term "Adoption of OPCS" × Signing the OPCS contract' significantly and negatively affects opportunistic behavior and its degree among certified farmers in pest control at the 1 and 5% levels, respectively. This suggests that signing the OPCS contract between principal and agent parties exerts a stronger restraining effect on opportunistic behavior in pest control in certified-vegetable areas.

In summary, hypothesis H2 is confirmed. The findings of this study are consistent with the conclusions reached by An et al. (2024) and Liu et al. (2024), who found that farmers' adoption of operational supervision measures during pesticide application and their purchase of pesticides on their own significantly reduce the increase in pesticide application intensity caused by outsourcing pest control services.

5 Discussion

Firstly, existing research on OPCS and farmers' pesticide use behavior only focuses on the impact of OPCS on pesticide application quantity, but there is a lack of research on whether pesticide use in OPCS operations complies with pest control standards in certified areas. In addition, current research on OPCS and farmers' pesticide use behavior has chosen research subjects to focus on wheat, rice, maize, or fruits, but there is a lack of research on vegetables as the object of study. According to statistics from the Ministry of Agriculture and Rural Affairs of China (PRC), the total pesticide residue exceedance rate for vegetables reaches 5.09%, significantly higher than that for other crops. Therefore, it is necessary to discuss the effect of OPCS on farmers' opportunistic behavior in pest control in vegetable certification areas. The results of this study indicate that OPCS can significantly restrain the opportunistic behavior of farmers in pest control regulations in certified-vegetable areas. This study not only greatly complements existing research on OPCS and farmers' pesticide use behavior, but also broadens and enriches relevant research perspectives.

Secondly, the conclusions of existing research on OPCS and farmers' pesticide use behavior remain controversial. Some studies suggest that OPCS can reduce the intensity of pesticide use (Ying and Xu, 2017; Yan et al., 2024; Wang et al., 2024), while others have found that OPCS has increased the intensity of pesticide use and exacerbated speculative behavior in pest control (Sun et al., 2018; Zheng and Zhang, 2022; Li et al., 2023; Liu et al., 2024). Therefore, it is important to explore the underlying reasons behind these conflicting findings. This study found that the controversy arises because previous research has largely overlooked the situational dependence of OPCS on pesticide application behavior. Specifically, under different internal and external constraints, the impact of OPCS on pesticide application behavior may vary. Therefore, this study applies "principal-agent" theory and incorporates factors such as service modalities provided by OPCS, the sources of pesticide supply, farmers' supervision of OPCS operations, and the signing of pest control service contracts into the "principal-agent" theory to investigate whether there are differences in the impacts of OPCS adoption on the opportunistic behavior of certified farmers in pest control under different "principal-agent" scenarios. The results reveal that OPCS has different restraining effects on the opportunistic behavior in pest control among farmers in certified-vegetables areas under different "principal-agent" scenarios. Specifically, in the implementation of OPCS, when farmers providing pesticides, supervising OPCS operations and signing pest control service contracts significantly strengthen the restraining effect of OPCS on the opportunistic behavior in pest control in certified-vegetables area. The results are in line with the findings of An et al. (2024) and Liu et al. (2024), who found that farmers' supervising OPCS of the pesticide application process and farmers' self-purchase of the pesticides significantly reduce the increase in pesticide application intensity due to OPCS.

Thirdly, Chen and Zhou (2022) found that pesticide reductions were more significant among farmers choosing the full-package service model compared to those opting for the half-package service model. This study demonstrates that different service modes provided by OPCS organizations exert different restraining effects on the opportunistic behavior and its degree in pest control among certified farmers. In particular, the full-package service model, the use of

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TABLE 8 Average treatment effect of different modes of OPCS on the opportunistic behavior among certified farmers in pest control.

Variable	Matching mode	OPCS selection type			OPCS technical support			OPCS settlement method		
		Full-package service model	Half-package service model	ATT	Advanced pesticide equipment	Traditional pesticide equipment	ATT	Settlement based on the single fixed service price	Settlement based on the service area	ATT
Opportunistic behavior	Nearest neighbor matching	0.642	0.856	−0.214***	0.417	0.690	−0.273***	0.479	0.826	−0.347***
	Caliper matching	0.564	0.863	−0.299***	0.421	0.675	−0.254***	0.479	0.849	−0.370***
	Radius matching	0.574	0.853	−0.279***	0.414	0.686	−0.272***	0.500	0.840	−0.340***
	Kernel matching	0.564	0.870	−0.306***	0.463	0.684	−0.221***	0.479	0.821	−0.342***
	Average value after matching	0.586	0.861	−0.275***	0.429	0.684	−0.255***	0.484	0.834	−0.350***
The degree of opportunistic behavior	Nearest neighbor matching	0.743	1.322	−0.579***	0.608	1.120	−0.512***	0.778	1.595	−0.817***
	Caliper matching	0.743	1.287	−0.544***	0.608	1.211	−0.603***	0.778	1.525	−0.747***
	Radius matching	0.775	1.371	−0.596***	0.634	1.104	−0.470***	0.829	1.531	−0.702***
	Kernel matching	0.743	1.327	−0.584***	0.608	1.112	−0.504***	0.778	1.508	−0.730***
	Average value after matching	0.751	1.327	−0.576***	0.615	1.137	−0.522***	0.791	1.540	−0.749***

TABLE 9 IV-probit model and IV ordered probit model estimation results.

Variables	The first stage	The second stage	
	T	Opportunistic behavior in pest control	The degree of opportunistic behavior in pest control
Adoption of OPCS	—	−2.011*** (0.784)	−4.188*** (1.194)
Proportion of villages adopting OPCS	0.532*** (0.114)	—	—
Control variable	Control	Control	Control
Sample size	644	644	644
The first stage *F*-value	19.61	—	—

TABLE 10 Moderating effect tests.

Variables	Opportunistic behavior			Degree of opportunistic behavior		
	Farmers' providing pesticides	Farmers supervision OPCS operations	Signing the OPCS contract	Farmers' providing pesticides	Farmers supervising OPCS operations	Signing OPCS contract
Adoption of OPCS	−0.073** (0.038)	−0.071*** (0.018)	−0.049*** (0.009)	−0.465*** (0.093)	−0.456*** (0.093)	−0.342*** (0.096)
Farmers' providing pesticides	−0.462*** (0.040)	—	—	−0.700** (0.347)	—	—
Adoption of OPCS × farmers' providing pesticides	−0.069* (0.026)	—	—	−0.679* (0.361)	—	—
Farmers' supervising OPCS operations	—	−0.892*** (0.090)	—	—	−0.532*** (0.040)	—
Adoption of OPCS × farmers' supervising OPCS operations	—	−0.073*** (0.028)	—	—	−0.327*** (0.098)	—
Signing the OPCS contract	—	—	−0.673*** (0.041)	—	—	−0.420*** (0.036)
Adoption of OPCS × signing the OPCS contract	—	—	−0.105*** (0.040)	—	—	−0.243** (0.098)
Control variables	Control	Control	Control	Control	Control	Control
Observed value	644	644	644	644	644	644
R^2	0.4630	0.4601	0.4631	0.7324	0.6314	0.6325

advanced pesticide equipment, and settlement methods based on a single fixed service price are more effective in significantly reducing the opportunistic behavior and its degree in pest control among certified farmers. The findings were similar to those of Chen and Zhou (2022).

However, this study is inevitably subject to certain limitations. Firstly, this study selected only the most typical advantageous vegetable production areas in the dry zones of Shaanxi, Gansu, and Ningxia provinces in China as the research areas. Thus, future research should expand the research area to encompass certified vegetable production areas nationwide, thereby making the findings more generalizable and better providing decision-making references for the management of pest control behaviors among smallholder farmers in China. Secondly, because this study used cross-sectional data, it is challenging to estimate the dynamic effects of OPCS adoption on opportunistic behavior among certified farmers in pest control. Therefore, future studies should conduct tracking surveys to better investigate the mechanisms underlying the dynamic effects of OPCS adoption on opportunistic behavior among farmers in pest control in certified vegetable areas.

6 Conclusions and policy implications

6.1 Conclusion

Under China's fundamental national context of a "big country with small farmers," OPCS is an important means for transforming the pest control methods of smallholder farmers in China to promote the high-quality development of agriculture. Therefore, based on the survey data collected from certified-vegetable areas in Shaanxi, Gansu, and Ningxia provinces (autonomous regions) in China this study investigates the impact of OPCS adoption on opportunistic behavior of pest control among farmers in the vegetable certification area. The main research conclusions are as follows:

Firstly, OPCS can significantly restrain the opportunistic behavior of farmers in pest control regulations in certified-vegetable areas. Specifically, if the farmers choose OPCS instead of self-pest control, the opportunistic behavior and its degree among certified farmers in pest control will be reduced by 28.61 and 11.82%, respectively.

Secondly, different OPCS service modes adopted by farmers have different restraining effects on their opportunistic behavior in pest control in certified-vegetable areas. Specifically, the certified farmers who actually use the half-package service model will reduce their opportunistic behavior and its degree in pest control by 29.30 and 68.34%, respectively, if they opt for the full-package service model. If an OPCS organization using traditional pesticide equipment switches to advanced pesticide equipment for pest control operations, the opportunistic behavior and its degree among certified farmers in pest control will be reduced by 22.77 and 57.32%, respectively. Furthermore, if an OPCS organization adopts a payment model based on a single fixed service price rather than the service area, the opportunistic behavior and its degree in pest control among certified farmers will decrease by 31.96 and 79.41%, respectively.

Thirdly, OPCS has different restrain on the opportunistic behavior in pest control among farmers under different "principal-agent" scenarios. Specifically, in the implementation of OPCS, farmers' providing pesticides, farmers' supervising OPCS operations, and signing a pest control service contract exert a stronger restraining effect on the opportunistic behavior in pest control in certified-vegetables areas.

6.2 Policy implications

The findings of this study have important policy implications for promoting the development of OPCS, reducing opportunistic behavior among farmers in pest control in certified-vegetable areas, and achieving high-quality agricultural development in China.

Firstly, since OPCS can effectively restrain opportunistic behavior and its degree among farmers in pest control in certified vegetable areas, the Chinese government should vigorously promote OPCS, especially in certified vegetable areas where self-pest control is still practiced. Meanwhile, the government should cultivate OPCS organizations based on local conditions to fully leverage their professional advantages and improve pest control effects. In addition, the supervision of OPCS organizations should be strengthened, their operational standards should be standardized, and service quality should be improved, thereby encouraging more farmers to adopt OPCS and increasing the coverage rate of OPCS.

Secondly, because different modes of OPCS adopted by farmers exert varying degrees of restraint on farmers' opportunistic behavior in pest control in certified-vegetable areas, the Chinese government and OPCS organizations should strengthen the training and guidance of OPCS personnel to improve their degree of specialization and service capacity, thereby enhancing pest control effectiveness. Meanwhile, OPCS organizations should optimize their service models, shifting from the half-package service model to the full-package service model with clearly defined rights and responsibilities for pest control. At the same time, the government should encourage the adoption of advanced pesticide application equipment, such as self-propelled pesticide sprayers or plant protection UAVs. In addition, OPCS organizations should optimize their settlement methods and encourage the use of fixed service price models to avoid directly linking the profitability of OPCS providers to the volume of work, thus avoiding opportunistic pest control behavior resulting from OPCS operations.

Thirdly, the influence of OPCS on the opportunistic behavior of farmers in pest control exhibits certain situational dependence. It was found that in certified vegetable production areas, farmers' providing pesticides, farmers' supervising OPCS operations, and signing a pest control service contract exert a stronger restraining effect on the opportunistic behavior in pest control. Therefore, in promoting OPCS, the Chinese government should encourage the commissioning and agent parties to sign a pest control service contract to clarify the rights and responsibilities of both sides. At the same time, the commissioning and agent parties should use the terms of the contract to regulate the pest control behaviors of OPCS organizations, thereby compelling them to comply with the pest control standards in certified vegetable areas. In addition, the Chinese government should encourage farmers to provide their pesticides and actively participate in the supervision of OPCS operations, while relevant agricultural departments should intensify pesticide residue sampling and testing to strictly penalize opportunistic behaviors by both farmers and OPCS organizations in pest control.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the patients/participants or patients/participants legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

XC: Data curation, Conceptualization, software, Methodology, Writing – original draft, Writing – review & editing, Investigation, Formal analysis. ZZ: Methodology, Investigation, Writing – review & editing. JZ: Methodology, Investigation, Writing – review & editing, Methodology. YW: Writing – review & editing, Visualization, Supervision, Funding acquisition.

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