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Bridging the Adoption Gap: Agricultural Outsourcing Services as an Extension Channel for Integrated Pest Management (IPM)

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Abstract:

Integrated pest management is a key pathway toward sustainable crop protection, yet its diffusion among smallholders remains uneven. Using survey data from 1,475 fruit and vegetable growers across China, this study examines whether and how agricultural outsourcing services promote its adoption. We distinguish between adoption decisions and adoption intensity, estimating their determinants using Logit and ordered Logit models. Outsourcing services positively affect adoption, though effects differ across stages. Deep ploughing, fertilization, and pollination services strongly relate to the adoption decision, whereas picking and plastic mulching services closely associate with adoption intensity. Furthermore, village collective action and machinery subsidies not only directly promote adoption but also strengthen the contribution of outsourcing services. Additionally, agricultural training, village-level social influence, and cultivated land quality positively relate to adoption outcomes. These findings suggest that outsourcing services function as a complementary extension channel by embedding technical knowledge into production services and lowering barriers to adopting sustainable practices. Promoting sustainable pest management therefore requires closer coordination among market-based service provision, community-level collective capacity, and

public policy support.

Key words: agricultural outsourcing services; integrated pest management; technology adoption; collective action; agricultural machinery subsidies

JEL Classification: Q12, Q58, O13

Introduction

As one of the world's largest agricultural producers, China faces a persistent dual challenge: safeguarding food security while advancing environmentally sustainable agriculture. Crop diseases, insect pests, and weeds are estimated to reduce yields by 15–25% annually and affect more than 400 million hectares of farmland. Within this broader challenge, the combined outbreaks of the “three major pests” have become a major threat to stable grain production (Gao et al., 2018; Zhang et al., 2023). Chemical control remains the dominant emergency response. Yet its continued reliance has generated growing concerns over pest resistance, rising application costs, and excessive pesticide residues, all of which constrain the green transformation of agriculture (Chen & Li, 2024; Panda & Dinakar, 2020; Piwowar, 2021). Against this background, Integrated Pest Management (IPM) has gained increasing attention as an alternative approach to pest governance (Hu et al., 2021; Kai et al., 2023; Yan et al., 2024). By combining biological control, ecological field management, and more precise pesticide use, IPM emphasizes prevention and coordinated regulation rather than routine chemical dependence (Angon et al., 2023; Gao et al., 2018; Yu et al., 2025). Previous studies show that this approach can reduce pesticide use and alleviate environmental pressure, thereby offering a potential pathway away from conventional chemical-intensive pest control (Cloyd et al., 2004;

Kabir & Rainis, 2014).

Despite these advantages, IPM adoption among smallholders remains limited. Existing research attributes this to the complexity of IPM practices, their relatively high implementation costs, and farmers' perceptions of production risk (Mariyono, 2018; Rustam, 2009). The gap between the technical promise of IPM and its limited uptake in practice points to a broader weakness in conventional agricultural extension systems. In this context, agricultural outsourcing services may provide a practical channel for overcoming adoption barriers. As a market-based arrangement, agricultural outsourcing enables smallholders to purchase specialized services for production tasks they are unable or unwilling to perform themselves. These services can cover multiple stages of production, including ploughing, sowing, fertilization, pollination, and harvesting. More importantly, outsourcing is not merely a substitute for family labor. When service providers embed standardized IPM practices into service delivery, outsourcing can also facilitate technology diffusion and knowledge transfer, lowering farmers' technical and informational barriers to adoption (Y. J. Chen et al., 2023; Deng et al., 2020; Lu et al., 2023; Xu et al., 2022). In this sense, outsourcing services may complement or even partially substitute for traditional extension by shifting technology delivery from administrative promotion to demand-based service provision (S. Chen et al., 2023; Shen et al., 2024).

The relationship between agricultural outsourcing and IPM adoption can be understood as a multi-level process involving individual farmers, local collective arrangements, and the broader policy environment (Cai et al., 2024; S. Chen et al., 2023; Vänninen et al., 2015). From the perspective of innovation diffusion theory, outsourcing providers can act as intermediaries

that translate technically demanding IPM practices into service products that are easier for farmers to access and use, thereby reducing cognitive and managerial barriers to adoption (Magnani & Elisabetta, 2006; Wonglimpiyarat & Yuberk, 2005). From the perspective of collective action theory, outsourcing can also help organize dispersed farmers into a shared service network, generating economies of scale and facilitating joint implementation of pest-control standards while spreading costs and risks across participants (Hergys et al., 2013; Kruijssen et al., 2009). From the perspective of institutional theory, these processes are further shaped by public policy. Government support, including machinery purchase subsidies, can encourage service providers to adopt advanced equipment and incorporate IPM-compatible technologies into their service packages, thereby creating an institutional environment conducive to wider IPM diffusion (Bunyaratavej et al., 2007; Wu et al., 2023). Empirical studies suggest that the interaction between subsidies and outsourcing has enabled service organizations to offer more integrated and technology-intensive “one-stop” services, allowing farmers to access green production technologies through market transactions rather than direct self-investment (Li et al., 2022; Yang et al., 2024).

However, several gaps remain in the existing literature. First, although the role of agricultural outsourcing services has received increasing attention, the mechanisms through which outsourcing affects IPM adoption are still insufficiently examined. In particular, little is known about whether and how village-level collective action and policy subsidies condition this relationship. Much of the current literature documents associations between outsourcing and technology adoption, but offers limited explanation of how social and institutional factors jointly shape farmers’ decisions. Second, existing studies have rarely integrated innovation

diffusion, collective action, and institutional theory into a unified analytical framework. As a result, they often fail to capture the multiple and interconnected drivers of technology adoption in smallholder agriculture. Third, most studies focus on whether farmers adopt IPM, while paying less attention to how intensively they adopt it once the initial decision has been made. Yet adoption is not a one-off choice; it is also reflected in the extent and continuity of use. Failing to distinguish between adoption decision and adoption intensity may therefore obscure important differences in farmers' behavioral responses and lead to an incomplete assessment of policy and market interventions.

This study contributes to the literature in three ways. First, it examines the distinct effects of agricultural outsourcing services on both farmers' decisions to adopt IPM and the intensity of subsequent adoption. Second, it develops a multi-level analytical framework that brings together innovation diffusion, collective action, and institutional theory to explain IPM adoption in smallholder settings. Third, it provides empirical evidence on how market-based service provision and policy support interact in shaping the diffusion of sustainable agricultural technologies.

Theoretical framework and research hypotheses

This section develops an integrated analytical framework to explain how agricultural outsourcing services affect farmers' adoption of IPM technology.

First, innovation diffusion theory provides a useful starting point for understanding farmers' technology adoption decisions at the individual level (Ruttan, 1996; Wonglimpiyarat & Yuberk, 2005). In this study, the theory is used to highlight the roles of knowledge transfer and learning

costs. Farmers' adoption of IPM is often constrained by information asymmetry and by the costs of acquiring and applying complex technical knowledge (Rong et al., 2023; Wyckhuys et al., 2017). Agricultural outsourcing services can ease these constraints. By embedding IPM practices in standardized and tradable service packages, service providers reduce the technical difficulty and cognitive burden associated with adoption (Abbas & Najam, 2025; Li & Fu, 2023; Steinke et al., 2020). In addition, large-scale service provision can make the effects of IPM more visible to farmers, reducing uncertainty and helping translate the expected benefits of the technology into observable economic outcomes (Magnani & Elisabetta, 2006; Piwowar, 2021). In this sense, outsourcing services may function as an alternative channel of agricultural extension by facilitating the transfer of technical knowledge and practical experience to farmers (Crane Droesch, 2017; Iost Filho et al., 2022).

Second, collective action theory helps explain the coordination problems that often arise in IPM adoption. Pest control has clear spillover effects, and its benefits are partly collective in nature. Under these conditions, individual farmers may have weak incentives to invest in control efforts when others can free-ride on the results, creating a gap between private incentives and socially desirable outcomes (Angon et al., 2023). From this perspective, agricultural outsourcing services are not only operational arrangements but also organizational mechanisms that help coordinate production and share risks among farmers (Huan & Zhan, 2022; Young et al., 2023). By enabling unified pest-control measures and more coordinated decision-making, outsourcing services can organize otherwise fragmented smallholders into a more coherent production arrangement. This can reduce the monitoring and coordination costs associated with free-riding, improve accountability in implementation, and generate economies

of scale in pest management and related inputs (Cai et al., 2024; Sahu & Choudhary, 2025; Zang et al., 2022). As a result, outsourcing services can help align individual incentives with collective outcomes, making IPM adoption more feasible in smallholder settings.

Finally, institutional theory helps explain how the broader policy environment shapes the relationship between outsourcing services and IPM adoption. Formal institutions, including government subsidies, can address market failures by changing relative input costs and reshaping incentives for both farmers and service providers (Mwale, 2023; Nan et al., 2023; Zhao et al., 2023). In particular, subsidies for agricultural machinery purchases can lower the fixed-cost barrier to acquiring IPM-compatible equipment and thus support the initial diffusion of the technology (Deng et al., 2024; Meng et al., 2024). At the same time, the effect of such subsidies depends on how effectively they are translated into actual production capacity. Here, agricultural outsourcing services may play an important moderating role. Where outsourcing markets are better developed, subsidies are more likely to be converted into accessible and usable services for farmers, thereby strengthening the policy effect and reducing the risk that public support fails to reach farm-level application (Sha et al., 2024; Shi et al., 2024). The adoption of IPM is therefore shaped not only by policy support itself, but also by the extent to which market-based service provision can transmit and operationalize that support (Camara & Savard, 2023; Zhang & Guo, 2024).

Taken together, the above discussion suggests that agricultural outsourcing services may promote IPM adoption through two main channels: by lowering farmers' learning and implementation costs at the individual level, and by reducing collective action problems at the village or community level. At the same time, the strength of this relationship may depend on

the policy environment, especially the availability of machinery purchase subsidies. Based on this framework, the following hypotheses are proposed:

H1: Agricultural outsourcing services have a significant positive effect on farmers' adoption of IPM technology.

H2: Village collective action positively moderates the relationship between agricultural outsourcing services and farmers' adoption of IPM technology.

H3: Subsidies for agricultural machinery purchases positively moderate the relationship between agricultural outsourcing services and farmers' adoption of IPM technology. The conceptual mechanism of the study is illustrated in Figure 1.

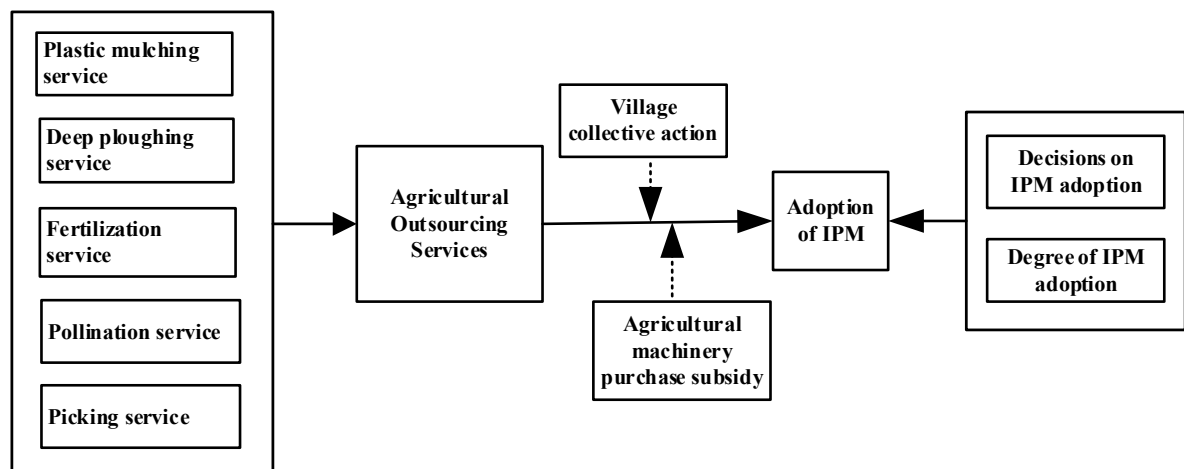


Figure 1: Mechanism diagram of this study

Data, Methods and Variable Selection

Data source

The data used in this study come from field surveys conducted by our research team in October 2019 and November 2020. The survey covered vegetable growers in Shandong,

Shaanxi, and Shanxi provinces. These provinces are important agricultural production areas in China and differ in levels of economic development and agricultural informatization, making them suitable for examining variation in technology adoption across regions, particularly in the context of the “13th Five-Year Plan for National Agricultural and Rural Informatization Development” issued by the Ministry of Agriculture in 2016.

To improve sample representativeness, the survey employed a multi-stage stratified random sampling strategy. The sampling proceeded in four steps. First, three prefecture-level cities were selected to reflect differences in economic conditions and informatization levels: Weifang in Shandong Province, Yuncheng in Shanxi Province, and Xi’an in Shaanxi Province. Second, four counties or districts within these cities were selected as the primary sampling units. Third, using county-level statistical information and the Probability Proportional to Size (PPS) method, townships were grouped into high-, medium-, and low-level categories according to local economic and informatization conditions, and one to two townships were randomly selected from each category. This yielded a sample covering two townships in Yanliang District (Xi’an), six to seven townships in Yuncheng District and Xia County (Shanxi), and seven townships in Shouguang District (Shandong). Finally, within each selected township, four to seven villages were randomly chosen, and 14 to 25 households were drawn from village rosters using systematic equal-interval sampling.

Several steps were taken to improve data quality. The questionnaire was revised following a pilot survey, and all interviewers received standardized training before the formal survey was implemented. Data were collected through one-on-one, face-to-face interviews. The questionnaire gathered information on farmers’ individual and household characteristics,

production practices, access to agricultural extension services, and information channels. After removing invalid, duplicate, and incomplete questionnaires, 1,475 valid observations were retained for the empirical analysis, including 800 households from Shandong, 310 from Shaanxi, and 365 from Shanxi. Figure 2 presents the survey areas covered by this study. The survey procedures adhered to the Declaration of Helsinki. Prior to each interview, trained enumerators obtained verbal informed consent from the respondents after explaining the study's purpose, the voluntary nature of participation, and the confidentiality of their anonymized responses.

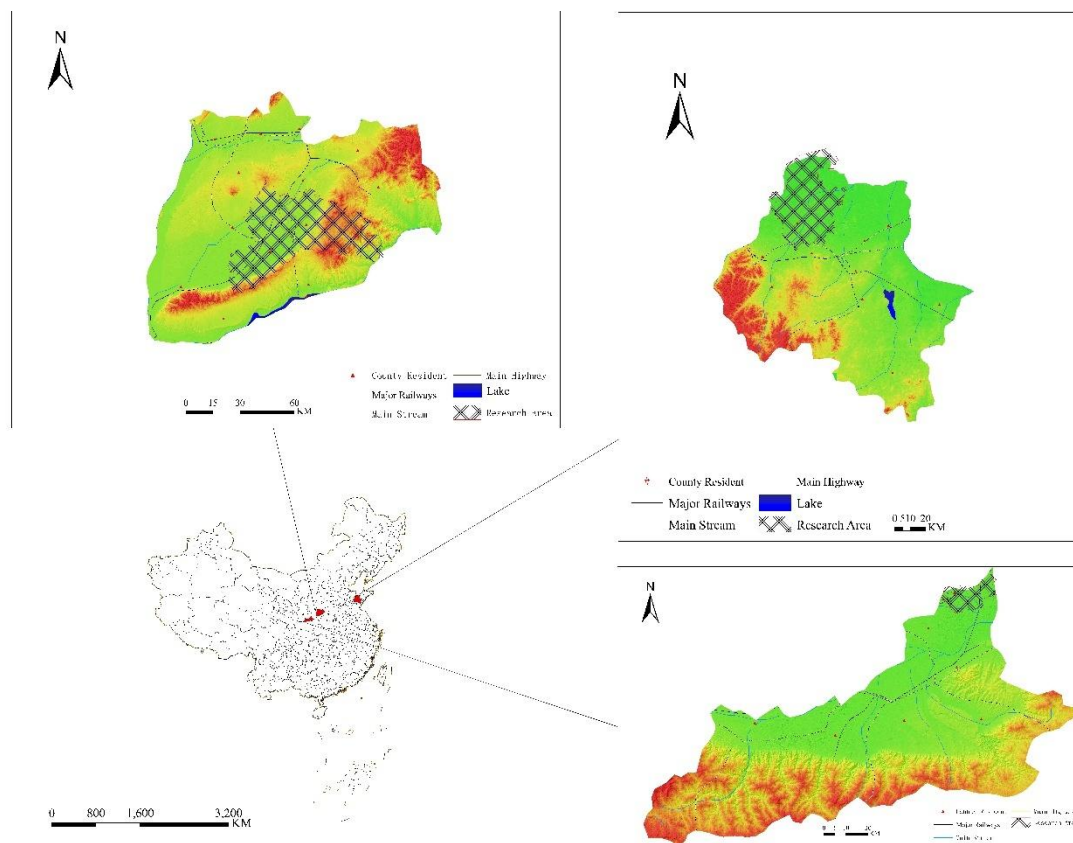


Figure 2: Survey area of this research

208 **Variable and descriptive statistics**

209 **Dependent variable**

210 IPM adoption is a multidimensional process that involves both the decision to adopt and
211 the extent to which adoption is implemented in practice. Following Farrar (2023), this study
212 measures IPM adoption from two complementary dimensions: adoption decision and adoption
213 intensity (Farrar, 2023).

214 **IPM adoption decision.** This binary variable captures whether a farmer has moved
215 beyond conventional chemical-dependent control and adopted a more integrated pest
216 management approach. Specifically, the survey identifies whether farmers use IPM-related
217 practices in three categories: (1) biological control, such as natural enemies or parasitic wasps;
218 (2) physical or mechanical control, such as sticky traps or insecticidal lamps; and (3) scientific
219 chemical or weed management, such as applying pesticides at appropriate times and dosages
220 or using manual weeding. Consistent with the existing literature, a farmer is classified as an
221 IPM adopter only if at least two of these categories are used. This criterion is intended to
222 distinguish integrated management from the isolated use of a single practice.

223 **IPM adoption intensity.** This variable measures the extent of IPM implementation
224 among farmers who adopt IPM practices (Angon et al., 2023). It is defined as the share of total
225 planting area under comprehensive IPM management. A larger value indicates deeper
226 implementation of IPM across the farm.

227 **Independent variables**

228 Agricultural outsourcing services are the main explanatory variables. Following Lu et al.
229 (2023), this study measures farmers' use of outsourcing services with five binary indicators

corresponding to major production stages: (1) plastic mulching, (2) deep ploughing, (3) pollination, (4) fertilization, and (5) harvesting (picking). These variables capture whether farmers purchase external services for specific farm operations. In practical terms, outsourcing may help relieve household labour constraints and improve farmers' access to specialized production skills and green technologies supplied by professional service providers.

Moderating variables

Based on the theoretical framework, two moderating variables are included.

(1) Village collective action. This variable is measured by the frequency with which farmers participate in maintaining irrigation facilities. It is used as a proxy for collective action in rural communities, with a higher frequency indicating stronger cooperation and community-level coordination.

(2) Machinery purchase subsidies. This binary variable indicates whether the household has received government subsidies for purchasing agricultural machinery. It captures the role of formal policy support in shaping farmers' access to agricultural technologies.

Control variables

To reduce omitted-variable bias, the analysis controls for a range of individual, household, farm, and regional characteristics, drawing on existing studies such as Vänninen et al. (2015) and field observations from the survey area (Vänninen et al., 2015). Individual characteristics include the household head's gender, age, education, and planting experience. Household characteristics include whether the family has a village cadre member, whether it has participated in agricultural training, and whether it has purchased agricultural insurance. Farm characteristics include cultivated land quality and irrigation conditions. In addition, provincial

dummy variables are included to account for regional heterogeneity. Variable definitions and descriptive statistics are reported in Table 1.

Descriptive statistics

Table 1 reports the definitions and descriptive statistics for all variables. For the dependent variables, 52.9% of farmers are classified as IPM adopters (standard deviation = 0.499), suggesting considerable variation in adoption decisions across households. Among adopters, the average IPM adoption intensity is 58.4% of the planting area (standard deviation = 0.303), indicating substantial heterogeneity in the depth of implementation.

For the main explanatory variables, the use of agricultural outsourcing services differs considerably across production stages. According to Table 1, the adoption rates range from 15.1% for fertilization services to 72.3% for pollination services, indicating that farmers' demand for outsourced services varies by task. Regarding the moderating variables, the average frequency of participation in irrigation facility maintenance is 4.944 times, with a relatively large standard deviation of 12.246, which points to pronounced differences in collective action across villages. In addition, 54.7% of households report receiving machinery purchase subsidies, suggesting relatively broad policy coverage in the sample.

The control variables also reflect the general profile of smallholder households in the survey areas. The household head is male in 68.2% of the sample, with an average age of 51.3 years and an average of 7.5 years of schooling. Mean planting experience is 28.6 years. In addition, 37.8% of households report having a family member who serves as a village cadre, 30.6% have participated in agricultural training, and 41.5% have purchased agricultural insurance. Average scores for cultivated land quality and irrigation conditions are 2.721 and

2.449, respectively. Overall, these descriptive patterns suggest substantial heterogeneity in household characteristics, production conditions, and access to institutional support.

Table 1. Descriptive statistics of variables

Variable	Variable description	Minimum	Maximum	Mean	Standard deviation
Dependent variables					
Decisions on IPM adoption	Is IPM adopted? Yes =1, No =0.	0	1	0.529	0.499
Degree of IPM adoption	What is the proportion of planting area using IPM technology to the total planting area? (%)	0	1	0.584	0.303
Core explanatory variables					
Agricultural Outsourcing Services					
Plastic mulching service	Did you buy the plastic mulching service? Yes =1, No =0.	0	1	0.289	0.454
Deep ploughing service	Have you purchased the deep loosening of arable soils service? Yes =1, No =0.	0	1	0.628	0.483
Fertilization service	Have you purchased fertilization and application services? Yes =1, No =0.	0	1	0.151	0.358
Pollination service	Did you buy pollination service? Yes =1, No =0.	0	1	0.723	0.448
Picking service	Did you buy the picking service? Yes =1, No =0.	0	1	0.430	0.495
Village collective action	Average frequency (times) of labor paid by your family to maintain irrigation facilities.	0	200	4.944	12.246
Agricultural machinery purchase subsidy	Does your family have subsidies for purchasing and updating agricultural machinery? Yes =1, No =0.	0	1	0.547	0.498
Gender	Gender of head of household: male =0, female =1.	0	1	0.682	0.466
Age	Age of head of household (years old)	20	84	51.323	8.808
Degree of education	Education time of head of household (year)	0	16	7.514	3.183
Planting experience	Planting years of householder (year)	0	72	28.631	15.286
Village cadre member variable	Does anyone in the family serve as a village cadre? Yes =1, No =0.	0	1	0.378	0.485
Agricultural training	Does the family participate in agricultural technology training? Yes =1, No =0.	0	1	0.306	0.431
Agricultural insurance	Does the family buy agricultural insurance? Yes =1, No =0.	0	1	0.415	0.493
Cultivated land quality	Fertility of family soil: very bad =1, bad =2, average =3, relatively good =4, very good =5.	1	5	2.721	1.172

Irrigation conditions	Family irrigation conditions: very bad =1, bad =2, average =3, relatively good =4, very good =5.	1	5	2.449	1.088
Virtual variables in Shanxi province	The province where farmers are located is Shanxi Province =1, others =0.	0	1	0.247	0.432
Virtual variables in Shaanxi province	The province where farmers are located is Shaanxi Province =1, others =0.	0	1	0.210	0.408

278

279 **Results**

280 **Relationship between agricultural outsourcing services and IPM adoption**

281 We examine how agricultural outsourcing services influence farmers' adoption of
282 integrated pest management (IPM) using binary Logit and ordered Logit models. Table 2
283 presents the estimation results for adoption decisions and adoption intensity, respectively.

284 **Impact on IPM adoption decisions**

285 The results indicate that specific outsourcing services significantly shape farmers'
286 likelihood of adopting IPM. Deep ploughing services have a positive and significant effect at
287 the 5% level, suggesting that professional soil preparation improves structure and permeability,
288 creating favorable conditions for crop growth and inherently reducing pest incidence—
289 consistent with the IPM principle of prevention. Fertilization and pesticide application services
290 exert a strongly positive effect at the 1% level, implying that specialized providers can deliver
291 precise input management plans that minimize chemical overuse and environmental harm,
292 aligning with core IPM tenets. Pollination services also demonstrate a positive and significant
293 impact at the 5% level, highlighting how outsourcing can introduce advanced biotechnologies
294 to farmers' operations.

295 Among the control variables, participation in agricultural training positively and

significantly promotes IPM adoption at the 5% level. This finding underscores the role of extension programs in enhancing farmers' knowledge and practical skills for pest control, thereby improving confidence in adopting more complex sustainable practices (Brück et al., 2023). Agricultural experts and technicians further support this process by serving as knowledge intermediaries, guiding farmers toward environmentally friendly and efficient pest management techniques.

Impact on IPM adoption intensity

Assessing adoption intensity reveals that different outsourcing services also influence the depth of IPM implementation. Professional harvesting services significantly increase adoption intensity at the 5% level, likely because systematic monitoring during harvesting enables timely and appropriate pest management decisions. Plastic mulching services show a strong positive effect at the 1% level, indicating that mulching enhances soil moisture retention and weed suppression, which in turn provides a solid foundation for more intensive IPM practices (Bernues et al., 2022).

Regarding household characteristics, the educational level of household heads positively correlates with adoption intensity at the 5% level, suggesting that higher education facilitates understanding and execution of complex IPM methods. Additionally, households with village cadre members exhibit higher adoption intensity, significant at the 5% level. This underscores the role of political capital and social influence: families with formal political identities often better understand national agricultural policies and act as opinion leaders, fostering broader adoption within their networks.

Overall, these findings confirm Hypothesis 1: agricultural outsourcing services not only

support the decision to adopt IPM but also promote deeper implementation. The results emphasize the potential of combining market-based services with traditional extension efforts to advance sustainable agriculture.

321

322 **Table 2.** Influence of agricultural outsourcing services on IPM technology adoption

Variable	Decisions on IPM adoption				Degree of IPM adoption			
	Coefficient	Robust std. err.	Z	P> z	Coefficient t	Robust std. err.	Z	P> z
Deep ploughing service	0.250**	0.117	2.15	0.032	0.190	0.209	0.91	0.363
Fertilization and application service	1.188***	0.173	6.81	0.000	0.083	0.314	0.27	0.791
Pollination service	0.317**	0.126	2.52	0.012	0.095	0.237	0.40	0.690
Picking service	0.053	0.110	0.48	0.632	0.046**	0.217	2.11	0.035
Plastic mulching service	0.034	0.160	0.21	0.833	1.402***	0.386	3.64	0.000
Gender	0.073	0.130	0.56	0.576	-0.129	0.281	-0.46	0.645
Age	-0.005	0.006	-0.75	0.451	0.011	0.012	0.90	0.367
Degree of education	0.059	0.017	3.58	0.208	0.088**	0.039	2.28	0.022
Planting years	0.005	0.108	0.13	0.196	0.003	0.007	0.40	0.691
Village cadre member variable	0.124	0.113	1.10	0.271	0.441**	0.223	1.98	0.048
Agricultural training	0.255**	0.124	2.06	0.040	0.131	0.228	0.57	0.565
Agricultural insurance	0.179	0.115	1.55	0.120	0.081	0.219	0.37	0.711
Cultivated land quality	0.021	0.048	0.44	0.664	0.231***	0.089	2.60	0.009
Irrigation conditions	0.058	0.050	1.16	0.248	0.141	0.103	0.37	0.171
Is it in Shanxi?	0.574***	0.162	3.55	0.000	1.041***	0.313	3.33	0.001
Is it in Shaanxi?	0.337**	0.165	2.04	0.042	0.406	0.278	1.46	0.144
Pseudo R2	0.043				0.080			
Prob > chi2	0.000				0.000			
Log likelihood	-976.294				-364.648			
Number of obs.				1475				

323 Note: ***, ** and * represent the significance levels of 1% and 5% and 10% respectively.

324

325 Mechanism of agricultural outsourcing services in promoting IPM adoption

326 To investigate the underlying mechanisms, this study employs the moderation effect
 327 analysis framework proposed by Wen et al. (2005). We specifically examine the interaction
 328 effects between village collective action, agricultural machinery subsidies, agricultural
 329 outsourcing services, and IPM adoption. The objective is to determine whether collective

action and policy subsidies act as moderators that amplify the influence of outsourcing services on farmers' decision-making and adoption intensity. The regression model incorporating interaction terms is specified as follows:

$$Y_i = a_1 + a_2M + a_3U_i + \varepsilon_i \quad (1)$$

$$Y_1 = b_0 + b_1M + b_2U_1 + b_3(M \times U_1) + \varepsilon_1 \quad (2)$$

$$Y_2 = C_0 + C_1M + C_2U_2 + C_3(M \times U_2) + \varepsilon_2 \quad (3)$$

In the equation, Y_i denotes the dependent variable, M represents the core independent variable (agricultural outsourcing services), and U_i signifies the moderating variable. In equations (2) and (3), Y_1 and Y_2 represent IPM adoption decisions and adoption intensity, respectively. U_1 and U_2 denote village collective action and agricultural machinery purchase subsidies, respectively. The coefficients to be estimated are represented by Greek letters, while ε denotes the residual term. A significant coefficient for the interaction term. A significant coefficient for the interaction term (b_3 or C_3), coupled with an improvement in model fit (Pseudo R^2), indicates the presence of a significant moderating effect.

Moderating role of village collective action

Village collective action, measured as the average frequency of farmers' labor contributions to irrigation maintenance (Qiu et al. 2023), reflects community social capital and organizational capacity. As shown in Table 3, interaction terms between outsourcing services and village collective action significantly increase the probability of IPM adoption at the 5% level across models. Models incorporating interaction terms show higher Pseudo R^2 values than baseline models, confirming the presence of moderation. This suggests that the positive effects of outsourcing services are amplified in villages where farmers engage actively in collective

352 action.

353 For adoption intensity, Table 4 indicates that interactions between collective action and
 354 pollination, picking, and plastic mulching services are significantly positive at 5% or 10%
 355 levels. These results highlight that a community's collective capacity strengthens the depth of
 356 IPM implementation.

357 From a theoretical perspective, collective action fosters social learning and trust, reducing
 358 information asymmetry and perceived risk when adopting new technologies. Farmers can share
 359 experiences and validate IPM practices, lowering cognitive barriers. Collective action also
 360 enhances bargaining power, enabling better collaboration with service providers to tailor
 361 technical support. Furthermore, visible success by leading farmers generates peer effects,
 362 accelerating technology diffusion within the village network.

363 In sum, village collective action serves as a critical social moderator, reinforcing the
 364 impact of agricultural outsourcing services on both IPM adoption decisions and
 365 implementation intensity, supporting Hypothesis 2.

366

367 **Table 3.** Agricultural outsourcing services, village collective action and IPM Adoption decision

Variable	Decisions on IPM adoption									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Village collective action	0.003 (0.004)	0.039* (0.021)	0.002 (0.004)	0.005 (0.005)	0.003(0. 004)	0.016 (0.007)	0.003 (0.004)	0.009(0. 008)	0.003 (0.004)	0.009 (0.009)
Deep ploughing service	0.280** (0.113)	0.286** (0.114)								
Deep ploughing service× Village collective action		0.048** (0.021)								
Fertilization and application service			1.185*** (0.170)	1.383*** (0.203)						

Fertilization and application service ×Village collective action				0.034** (0.016)						
Pollination service					0.280** (0.113)	0.285** (0.113)				
Pollination service ×Village collective action						0.019** (0.008)				
Picking service							0.266* (0.142)	0.282** (0.143)		
Picking service ×Village collective action								0.021* (0.012)		
Plastic mulching service									0.264* (0.155)	0.264* (0.156)
Plastic mulching service× Village collective action										0.020* (0.011)
Control variable					Controlled					
Wald value	24.87	30.69	63.21	65.24	24.87	30.26	22.24	25.37	21.58	24.82
Prob > chi2	0.024	0.006	0.000	0.000	0.024	0.007	0.052	0.031	0.062	0.036
Pseudo R2	0.013	0.017	0.037	0.039	0.013	0.015	0.011	0.014	0.011	0.014
Numbers					1475					

368 Note: * * *, * * and * represent that the estimated results are significant at the level of 1%, 5% and 10%
369 respectively.

370

371 **Table 4.** Agricultural outsourcing services, village collective action and IPM adoption intensity

Variable	Degree of IPM adoption									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Village collective action	0.005 (0.007)	0.026 (0.040)	0.005 (0.007)	0.002 (0.007)	0.005 (0.007)	0.030 (0.020)	0.006 (0.007)	0.020** (0.008)	0.006 (0.007)	0.022*** (0.008)
Deep ploughing service	0.368* (0.203)	0.358* (0.204)								
Deep ploughing service× Village collective action		0.035 (0.041)								
Fertilization service			0.258 (0.310)	0.464 (0.368)						
Fertilization service ×Village collective action				0.029 (0.019)						
Pollination service					0.368* (0.203)	0.369* (0.204)				
Pollination service ×Village collective action						0.038* (0.021)				
Picking service							0.512** (0.218)	0.274 (0.239)		
Picking service ×Village collective action								0.051* (0.028)		

collective action										
Plastic mulching service								1.510***	1.467***	
								(0.379)	(0.378)	
Plastic mulching service× Village collective action									0.057**	
									(0.027)	
Control variable						Controlled				
Wald value	45.38	47.67	41.59	42.89	45.38	46.92	46.30	51.40	54.12	60.81
Prob > chi2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pseudo R2	0.051	0.053	0.048	0.051	0.051	0.055	0.055	0.062	0.074	0.085
Numbers						1475				

372 Note: * * *, * * and * represent that the estimated results are significant at the level of 1%, 5% and 10%
373 respectively.

374

375 The moderating role of agricultural machinery purchase subsidies

376 Agricultural machinery purchase subsidies are an important policy instrument through
377 which the state supports farmers and agricultural service organizations in acquiring and
378 upgrading key production equipment. By lowering the cost of mechanization, these subsidies
379 reduce financial constraints in the modernization of agricultural production (Deng et al., 2024).
380 In this study, agricultural machinery purchase subsidies are treated as a moderating variable to
381 examine whether they strengthen the effect of agricultural outsourcing services on IPM
382 adoption. The interaction results are reported in Tables 5 and 6.

383 As shown in Table 5, the interaction terms between most agricultural outsourcing services
384 and machinery purchase subsidies are positive and statistically significant in the IPM adoption
385 decision models. The only exception is pollination services, for which the interaction term is
386 not statistically significant. Compared with the baseline models, the specifications including
387 interaction terms report higher Pseudo R2 values, pointing to a clear moderating effect. In
388 substantive terms, machinery subsidies strengthen the positive association between outsourcing
389 services and farmers' decisions to adopt IPM, especially for deep ploughing, fertilization,

picking, and plastic mulching services.

A similar pattern appears in the adoption intensity models. Table 6 shows that the interaction terms between all categories of agricultural outsourcing services and machinery purchase subsidies are positive and significant at the 1% level. The increase in Pseudo R^2 is also more pronounced than in the decision models, indicating that subsidies play an even stronger role in deepening the implementation of IPM once adoption has occurred.

This pattern can be understood from the perspectives of institutional economics and technology diffusion. On the one hand, machinery purchase subsidies reduce the fixed costs associated with advanced equipment, making it easier for both service providers and farmers to access machinery embedded with precision functions, such as targeted spraying and pest monitoring. These functions are closely related to the practical implementation of IPM. On the other hand, subsidies and outsourcing services are complementary. Subsidies improve access to machinery, while outsourcing services provide the technical knowledge and operational capacity needed to use that machinery effectively. In this sense, the policy provides the material basis, whereas the service system translates that basis into actual pest management practices. In addition, by lowering the cost of trying new production methods, subsidies reduce the risks associated with technological adjustment and make farmers more willing to engage with outsourcing services beyond conventional chemical control.

Taken together, the results show that agricultural machinery purchase subsidies strengthen the contribution of outsourcing services to both the decision to adopt IPM and the extent of its implementation, which supports Hypothesis 3.

412 **Table 5.** Agricultural outsourcing services, agricultural machinery purchase subsidy and IPM
413 adoption decision

Variable	Decisions on IPM adoption									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Agricultural machinery purchase subsidy	0.255* (0.141)	0.413** (0.203)	0.313** (0.143)	0.306** (0.145)	0.265* (0.157)	0.270* (0.157)	0.273** (0.142)	0.247* (0.144)	0.268* (0.142)	0.230 (0.152)
Deep ploughing service	0.268** (0.113)	0.487** (0.232)								
Deep ploughing service× Agricultural machinery purchase subsidy		0.233*(0.120)								
Fertilization service			1.201** * (0.170)	1.195** * (0.171)						
Fertilization service× Agricultural machinery purchase subsidy				0.569** * (0.164)						
Pollination service					0.318** (0.124)	0.285* (0.130)				
Pollination service× Agricultural machinery purchase subsidy						0.098 (0.122)				
Picking service							0.055 (0.107)	0.045 (0.108)		
Picking service× Agricultural machinery purchase subsidy								0.031* (0.017)		
Plastic mulching service									0.267* (0.155)	0.266* (0.155)
Plastic mulching service× Agricultural machinery purchase subsidy										0.211* (0.119)
Control variable					Controlled					
Wald value	27.39	28.34	67.85	68.02	26.75	27.11	22.00	23.18	24.59	25.32
Prob > chi2	0.011	0.013	0.000	0.000	0.013	0.018	0.055	0.057	0.026	0.031
Pseudo R2	0.013	0.015	0.039	0.039	0.014	0.014	0.011	0.012	0.013	0.013
Numbers					1475					

414 Note: * * *, * * and * represent that the estimated results are significant at the level of 1%, 5% and 10%
415 respectively.

416

417

418 **Table 6.** Agricultural outsourcing services, agricultural machinery purchase subsidy and IPM

419 adoption intensity

Variable	Degree of IPM adoption									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Agricultural machinery purchase subsidy	0.381* (0.215)	0.363* (0.214)	0.415* (0.214)	0.387* (0.210)	0.409* (0.212)	0.387* (0.209)	0.410** (0.212)	0.376* (0.209)	0.354* (0.210)	0.353* (0.211)
Deep ploughing service	0.336 (0.205)	0.214 (0.212)								
Deep ploughing service× Agricultural machinery purchase subsidy		1.286* ** (0.372)								
Fertilization service			0.267 (0.312)	0.122 (0.310)						
Fertilization services× Agricultural machinery purchase subsidy				1.318* ** (0.359)						
Pollination service					0.102 (0.238)	0.031 (0.236)				
Pollination service× Agricultural machinery purchase subsidy						1.338* ** (0.368)				
Picking service							0.503** (0.214)	0.455** (0.215)		
Picking service× Agricultural machinery purchase subsidy								1.286** * (0.359)		
Plastic mulching service									1.461* ** (0.374)	1.549* (0.117)
Plastic mulching service× Agricultural machinery purchase subsidy										0.512* *(0.221)
Control variable					Controlled					
Wald value	49.44	57.05	44.74	52.85	44.36	52.80	49.88	55.92	55.94	56.08
Prob > chi2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pseudo R2	0.054	0.073	0.052	0.072	0.051	0.071	0.058	0.077	0.075	0.076
Numbers					1475					

420 Note: * * *, * * and * represent that the estimated results are significant at the level of 1%, 5% and 10%
421 respectively.

422

423 Discussion

424 This study examines the drivers of Integrated Pest Management adoption among fruit and
425 vegetable farmers in eastern, central, and western China, with particular attention to
426 agricultural outsourcing services, village collective action, and agricultural machinery
427 purchase subsidies. The results point to a joint role of market provision, local social
428 organization, and policy support in shaping farmers' adoption of sustainable agricultural

429 practices.

430 First, the findings show that agricultural outsourcing services matter not only for whether
431 farmers adopt IPM, but also for how intensively they implement it. Deep ploughing,
432 fertilization, and pollination services are more closely associated with the initial adoption
433 decision, while picking and plastic mulching services are more relevant to the depth of adoption.
434 This difference is meaningful. Some services appear to lower the threshold for trying IPM by
435 embedding technical knowledge directly into production activities, whereas others are more
436 closely related to the continued and more comprehensive use of IPM practices. In that sense,
437 outsourcing services do more than replace labor. They also function as carriers of knowledge,
438 standardized procedures, and practical experience. For farmers who lack the time, skills, or
439 equipment to implement IPM independently, these services provide an accessible pathway into
440 sustainable production. This is broadly consistent with Aremu et al. (2024), and it also suggests
441 that market-based services can complement conventional public extension systems rather than
442 simply operate alongside them.

443 Second, the results highlight that the effect of outsourcing services is not uniform across
444 social contexts. Village collective action strengthens the relationship between outsourcing
445 services and IPM adoption, especially in villages where farmers are more actively involved in
446 collective activities. This finding points to the importance of community-level coordination in
447 the adoption of environmentally friendly technologies. IPM is not a purely individual decision.
448 Its implementation often depends on information sharing, observation of others' practices, and
449 confidence that new methods will work under local conditions. Collective action helps create
450 these conditions. It reduces uncertainty, facilitates learning, and makes it easier for farmers to

coordinate around common production problems. Seen from this angle, the adoption of IPM is shaped not only by individual cost-benefit calculations but also by the quality of local social relations and the organizational capacity of the village. This interpretation is in line with Gao et al. (2018), who stress the need to connect top-down policy arrangements with bottom-up community participation.

Third, agricultural machinery purchase subsidies also play an important reinforcing role. The estimates show that subsidies strengthen the positive contribution of outsourcing services to both the adoption decision and adoption intensity. This points to a complementary relationship between policy and market provision. Subsidies reduce the financial barrier to mechanization, while outsourcing services make the resulting equipment and technologies usable in practice. For smallholders, access to machinery alone may not be enough if they lack the technical capacity to operate it effectively. By contrast, when machinery support is combined with service provision, the adoption of IPM becomes more feasible and less risky. The results therefore suggest that policy incentives are most effective when they do not operate in isolation, but instead interact with existing service systems.

Among the control variables, agricultural training remains important for the adoption decision, which underlines the continued relevance of agricultural education and extension. Training improves farmers' understanding of pest control strategies and the broader ecological and economic logic of IPM, making them more prepared to move away from conventional chemical-intensive practices. The positive effect of village cadre membership on adoption intensity also deserves attention. In many rural settings, local cadres continue to shape access to information, policy interpretation, and the diffusion of new practices. Their role in this study

is broadly consistent with the idea that local leaders can act as intermediaries between formal policy goals and farmers' everyday production decisions. In addition, better cultivated land quality is positively associated with adoption intensity, suggesting that farmers are more likely to deepen investment in IPM when production conditions are favorable and returns to sustainable management are more visible. This is consistent with Shi et al. (2024) and points to the interaction between human capital, local influence, and production endowments.

Overall, the findings suggest that the adoption of IPM cannot be explained by a single mechanism. Market services, village-level collective capacity, and public policy each matter, but their effects are strongest when they work together. For agricultural extension, this implies that promoting sustainable production requires more than the simple transfer of technical information. What matters is whether farmers can access services, whether village institutions support coordination and learning, and whether policy instruments reduce the costs and risks of change.

Conclusion and future prospect

This study shows that agricultural outsourcing services are an important force behind the adoption of Integrated Pest Management. Core outsourced services, including deep ploughing, fertilization, and pollination, are positively associated with farmers' decisions to adopt IPM, while services such as picking and plastic mulching are more closely related to the intensity of adoption. These findings indicate that outsourcing services can serve as an effective channel through which sustainable technologies are translated into farm-level practice. In this respect, they perform part of the function traditionally assigned to agricultural extension.

The results also show that village collective action and agricultural machinery purchase subsidies strengthen the role of outsourcing services. Collective action supports social learning and coordination, while subsidies reduce the financial threshold associated with mechanized and technology-intensive production. Their combined effect suggests that IPM adoption is more likely to expand where market services are embedded in supportive community structures and backed by policy incentives. The effectiveness of agricultural extension therefore depends not only on the availability of technical solutions, but also on the local institutional environment in which those solutions are introduced.

The control variables further indicate that human capital and social influence remain central. Agricultural training improves farmers' capacity to make informed production decisions, while village cadres appear to play an important role in deepening adoption. The positive association between land quality and IPM intensity suggests that sustainable technology adoption is also shaped by production conditions and long-term expectations regarding returns to ecological management.

These findings carry several policy implications. Rather than treating outsourcing, collective organization, and subsidies as separate policy domains, a more integrated governance approach is needed. One practical direction is to cultivate medium-sized agricultural business entities as localized service hubs that can package advanced technologies into forms accessible to smallholders. Another is to shift part of subsidy implementation from atomized household-based support toward more collective and project-based arrangements, which may better match the scale and coordination requirements of sustainable production. At the same time, public intervention should continue to invest in farmers' knowledge and

516 decision-making capacity, while making fuller use of village-level actors in the dissemination
517 of sustainable practices.

518 This study also leaves room for further work. Future research could move beyond the
519 static distinction between adoption and non-adoption and examine whether IPM use is
520 sustained over time, whether intensity changes across production cycles, and under what
521 conditions farmers discontinue adoption. It would also be valuable to explore how IPM
522 interacts with other innovations, including digital agriculture and data-based agricultural
523 services. More broadly, future studies could pay greater attention to the incentives of service
524 providers themselves and to the broader governance relationships among state actors, markets,
525 and rural communities. Such work would help clarify how sustainable agricultural technologies
526 can be promoted more effectively across different institutional settings.

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534 We confirm that “deepseek” was only used for grammar refining and grammar polishing in the
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539 **CRedit authorship contribution statement**

540 Conceptualization, Tianzhi Gao; methodology, Hui Feng; investigation, Hui Feng and Fei Yuan;
541 writing—original draft preparation, Tianzhi Gao; writing—review and editing, Hui Feng and
542 Qian Lu.

543 **Consent for publication**

544 Not applicable.

545 **Declaration of Competing Interest**

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

548 **Data availability statement**

549 The data that support the findings of this study are available from the corresponding author
550 upon reasonable request.

551 **Ethical approval**

552 Ethical approval was not required for this study in accordance with Article 32 of the
553 Administrative Measures for Ethical Review of Life Science and Medical Research I
554 nvolving Humans in China ([https://www.gov.cn/zhengce/zhengceku/2023-02/28/content_5](https://www.gov.cn/zhengce/zhengceku/2023-02/28/content_5743658.htm)
555 743658.htm). Article 32 states that studies using legally obtained public data, observati
556 onal data generated without interfering with public behavior, or anonymized informatio
557 n may be exempt from ethical review, provided that they do not cause harm to indivi
558 duals and do not involve sensitive personal information or commercial interests. This
559 study was based on an anonymous, non-interventional household questionnaire survey

and did not involve any biomedical intervention, clinical trial, animal experiment, or collection of biological samples.

Informed consent

Prior to each interview, trained enumerators verbally informed respondents in Chinese about the purpose of the study, the academic use of the data, the voluntary nature of participation, and the anonymous and confidential treatment of their responses. Respondents were also informed that they could refuse to answer any question or withdraw from the interview at any time without any negative consequence. After this explanation, verbal informed consent was obtained from each respondent before the questionnaire was administered. Written consent was not collected because the survey was anonymous, involved minimal risk, and was conducted through face-to-face interviews in rural communities where some respondents might have limited literacy or might be reluctant to sign written documents. The interview proceeded only when the respondent clearly agreed to participate. All collected data were anonymized and used solely for academic research purposes.

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