

Article

External Intervention, Farmer Perception and Advanced Agricultural Technology Adoption: Micro Evidence from Grain Farmers in China

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Abstract

The diffusion and application of advanced and applicable agricultural technologies serve as critical support for realizing the green transition and promoting high-quality agricultural development. This study constructs a two-dimensional analytical framework encompassing external intervention, internal motivation, and behavioral response. Based on micro survey data collected from 675 rice-growing households across Jiangsu Province, China, this study empirically examines the impact of agricultural technology extension services, a representative form of external intervention, on farmers' adoption of the One-time Fertilization Technology for Mechanized Transplanting Rice (OFT), and its underlying mechanisms. The results demonstrate that external intervention acts as the core exogenous driver of farmers' adoption of advanced agricultural technologies, with its transmission effect dependent on the mediating and moderating functions of farmers' internal perceptions. Agricultural technology extension services facilitate technology adoption primarily by improving farmers' technical cognition and enhancing their value perception. Notably, the effectiveness of extension services is more pronounced among farmers with higher levels of risk perception. The effect of external intervention is jointly shaped by the endowment of regional extension resources and the inherent demand of farmers, with significantly stronger extension effects observed in less developed major agricultural production areas compared to economically developed regions. This study concludes that promoting the adoption of advanced agricultural technologies requires sustained efforts to strengthen the supply of extension services, optimize the design of extension service content, implement differentiated extension strategies, and fully align with the characteristics of farmers' risk preferences and regional heterogeneity.

Keywords: agricultural technology extension service; technology adoption; external intervention; internal perception; mechanism analysis; OFT

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1. Introduction

Agricultural green transition is the core direction of high-quality agricultural development in China, and the diffusion and application of advanced and applicable agricultural technologies are critical support for realizing this green transition. For a long time, China's agricultural technology extension system has been characterized by government-led external intervention, which promotes the implementation of advanced technologies

through top-down technology supply [1]. However, there are widespread practical mismatches between technology supply and farmers' demand, as well as a disconnect between extension investment and adoption effect [2]. Taking the One-time Fertilization Technology for Mechanized Transplanting Rice (OFT) as an example, this technology can reduce chemical fertilizer application by 15–20% during the whole growth period, cut labor input by more than 50%, and increase yield by 3–5% compared with conventional fertilization practices [3]. OFT is characterized by a single application that covers the entire crop growth period, which not only effectively addresses the spatiotemporal mismatch inherent in traditional fertilization practices but also improves resource use efficiency through the integration of agricultural machinery and agronomic management, providing a feasible solution for chemical fertilizer reduction and efficiency enhancement. Nevertheless, the promotion and application of such advanced agricultural technologies have not reached the expected scale and present significant regional disparities. In 2022, the national application area of OFT only accounted for 8.3% of the total rice planting area, concentrated in pioneer demonstration regions such as Jiangsu and Anhui provinces, with the regional adoption rate difference exceeding 20 percentage points [3].

Existing studies mostly analyze technology adoption issues from a single perspective. One strand of research focuses on the implementation effects of external policies such as agricultural technology extension, emphasizing the roles of external intervention in information transmission and resource allocation [4,5]. The other strand examines the impacts of farmers' individual characteristics and cognitive factors on adoption decisions, highlighting the constraining effect of internal perception [6,7]. However, these two perspectives are relatively isolated, failing to systematically explain the synergistic mechanism between external intervention and internal perception, and making it difficult to account for the widely observed phenomenon that farmers' adoption behaviors vary significantly even when the same promotion policy is implemented. In fact, farmers' technology adoption decisions are the result of the combined effect of external policy environment and internal decision-making logic. As a form of external intervention, agricultural technology extension alters the external constraints of farmers' decision-making through multiple pathways, including reducing information barriers, providing technical support, and lowering adoption risks. Meanwhile, farmers' technical cognition, value perception, and risk perception serve as core components of internal perception, which directly determine their evaluation of the technology and willingness to adopt it [8]. Analysis conducted from only a single perspective cannot fully reveal the internal mechanism of technology adoption, nor can it provide an accurate empirical basis for the optimization of agricultural technology promotion policies.

Against this background, this study develops a two-dimensional analytical framework encompassing external intervention, internal motivation, and behavioral response. Taking OFT as the research subject, this study uses micro survey data from 675 rice-growing households in Jiangsu Province to systematically analyze the dual mechanism of external intervention from agricultural technology extension and farmers' internal perception on technology adoption. This study makes three marginal contributions to the existing literature. First, it breaks through the limitations of the single analytical perspective by constructing a two-dimensional analytical framework to systematically explain the synergistic mechanism between external intervention and internal perception. Second, it clarifies the heterogeneous roles of three dimensions of internal perception, revealing the respective mechanisms of technical cognition, value perception, and risk perception in shaping adoption decisions. Third, it conducts a heterogeneity analysis across regions to provide empirical evidence for the formulation of differentiated promotion policies. As one of the major rice-producing regions in China, Jiangsu Province has significant differences across its internal regions in terms of economic development level, agricultural re-

source endowment, and agricultural technology extension system, providing an ideal research scenario for examining the mechanism through which external intervention and internal perception drive technology adoption.

2. Literature Review and Theoretical Analysis

2.1. Literature Review

Farmers' technology adoption behavior is a classic research topic in agricultural economics and technological innovation studies. Existing studies are mainly developed along two strands of literature. The first strand adopts the external intervention perspective, focusing on the impacts of external factors such as agricultural technology extension, policy subsidies, and socialized services on technology adoption [1,4,5]. The second strand follows the internal perception perspective, exploring how individual characteristics of farmers, including technical cognition, value judgment, and risk preference, affect their decision-making [6,7,9].

From the external intervention perspective, a large body of research confirms that agricultural technology extension services are the core external factor driving technology adoption [10–12]. Some studies argue that access to agricultural technology extension services not only helps alleviate the negative impacts caused by low efficiency in the agricultural technology information market, but also facilitates farmers' access to new technologies and new products [13]. Such access helps improve farmers' agricultural production and management capabilities, and further promotes their technology adoption decisions [14]. Other studies suggest that agricultural technology extension services have minimal or no significant effect on farmers' technology adoption decisions, and explain the reasons from multiple aspects. The first reason relates to farmer heterogeneity. Due to heterogeneous factors such as gaps in farmers' economic status, some smallholder farmers cannot access corresponding technologies even if they receive agricultural technology extension services. This indicates that agricultural technology extension services tend to focus more on large-scale farmers, leading to severe marginalization of smallholder farmers [13]. The second reason lies in regional differences. Agricultural technology extension services vary across different regions [15], resulting in limited positive effects of such services in some areas. These inconsistent findings indicate that the relationship between agricultural technology extension services and farmers' technology adoption decisions remains controversial.

From the internal perception perspective, farmers' technical cognition, value perception, and risk perception are the key internal factors determining adoption decisions [16]. Technical cognition serves as the premise of technology adoption, and farmers' understanding of technical principles and operational specifications directly affects their willingness to adopt [17]. Value perception reflects farmers' judgment of technical benefits, and adoption behavior occurs only when farmers believe that the expected benefits of technology adoption exceed the costs [18]. Risk perception constitutes the constraint condition for decision-making, and the uncertainty associated with agricultural technology adoption will inhibit the adoption willingness of risk-averse farmers. It should be noted that farmers' internal perception level is also closely related to their own resource endowment conditions. Generally, younger and more educated farmers have stronger learning ability and risk perception, and are more inclined to adopt new technologies [2]. From the perspective of household operation characteristics, factors such as operation scale, land fragmentation degree, and the proportion of agricultural income have important impacts on technology adoption [4,19]. Large-scale operation entities have the advantages of economies of scale, leading to lower marginal costs of new technology adoption and a stronger willingness to adopt.

Existing studies have provided a rich theoretical basis for understanding technology adoption behavior, but the two perspectives are relatively independent, lacking a systematic analysis of the interactive relationship between external intervention and internal perception. In fact, as a form of external intervention, the core role of agricultural technology extension is not only to directly reduce the adoption threshold, but more importantly, to indirectly drive adoption decisions by improving farmers' internal perception level.

2.2. Theoretical Analysis

Based on existing research, this paper constructs a three-dimensional analytical logic consisting of external intervention, internal motivation, and behavioral response. By integrating the innovation diffusion theory, technology acceptance model and theory of planned behavior, the paper develops a theoretical analytical framework for the joint impact of agricultural technology extension services and farmers' perception characteristics on technology adoption, with a focus on revealing the interactive relationship and functional mechanism between external policy intervention and farmers' internal decision-making logic. The analytical framework is illustrated in Figure 1.

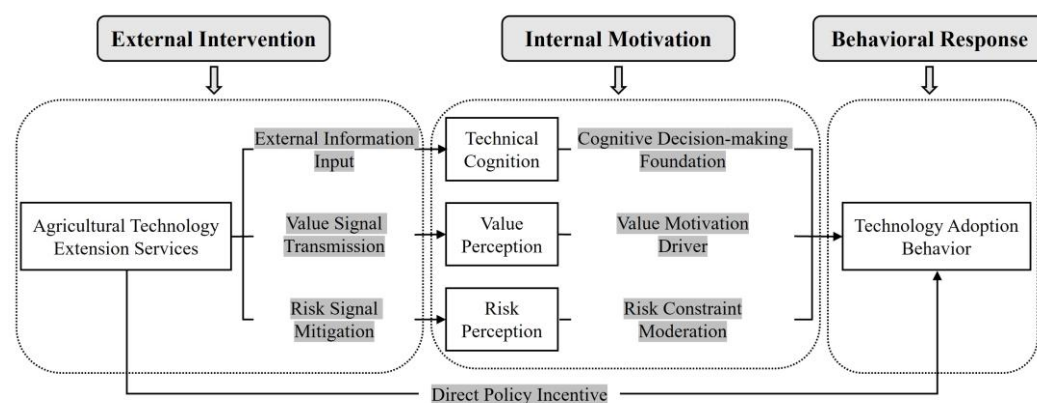


Figure 1. Theoretical analysis framework.

Farmers' adoption decisions regarding advanced agricultural technologies result from the synergistic effect of external policy interventions and internal perception characteristics. From the perspective of decision-making logic, agricultural technology extension services, as a typical exogenous policy intervention, act as the supplier of technical information. Their functions include reducing farmers' information search costs, alleviating information asymmetry, and modifying the external constraint conditions for technology adoption, thus forming the exogenous driving force of decision-making [20,21]. As internal psychological variables, farmers' perception characteristics serve as the demanders and processors of technical information, which determine the conversion efficiency of external information and the final decision outcomes, constituting the endogenous pulling force of decision-making [16]. The functional logics of the two are essentially different. External interventions have public good attributes and policy guidance characteristics, with inclusive effects but heterogeneous marginal effects across different farmer groups. Internal perceptions are characterized by individual heterogeneity and subjectivity, playing a decisive role in decision-making. External interventions can only exert maximum effectiveness when they match farmers' internal perception characteristics. However, there are significant differences in the functional logics among the three types of internal perception variables. Technology cognition and value perception act as the transmission channels for the conversion of external interventions into behaviors, determining whether the effect of extension services can be implemented. Risk perception serves as the bound-

any condition for the effectiveness of external interventions, determining the intensity of the effect of extension services.

2.2.1. Direct Impacts of External Interventions

According to the innovation diffusion theory, agricultural technology extension services act as a bridge connecting technology R&D and production application. They represent the core policy instrument to address market failure in technology diffusion and promote the popularization of advanced agricultural technologies. The direct promoting effect of extension services on technology adoption is reflected in three dimensions.

The first dimension is the information transmission effect. Advanced agricultural technologies are mostly integrated and complex, with typical attributes of experience goods. It is difficult for farmers to understand the core characteristics and application effects of such technologies through conventional channels. Agricultural technology extension services deliver technical information to farmers through multiple channels, which effectively fills farmers' information gaps and reduces information barriers to technology adoption [2].

The second dimension is the cost reduction effect. Agricultural technology extension services provide public services such as free technical training, on-site guidance and demonstration displays, which reduce farmers' technology learning costs and trial-and-error costs [13]. Meanwhile, the government endorsement attached to extension services can enhance farmers' trust in technologies and lower the psychological costs of technology adoption.

The third dimension is the resource empowerment effect. Agricultural technology extension services are often bundled with policy support, including technical subsidies, supporting services and demonstration projects [13]. These supporting measures can directly improve the external constraint conditions for farmers' technology adoption and enhance farmers' capability to adopt technologies.

The above effects jointly constitute the direct driving role of agricultural technology extension services in technology adoption. Based on this analysis, Research Hypothesis 1 is proposed.

Hypothesis 1. *As an external intervention instrument, agricultural technology extension services have a significant positive impact on farmers' adoption of advanced agricultural technologies.*

2.2.2. Mediating Effect of Internal Perception: The Roles of Technology Cognition and Value Perception

As an external information input, agricultural technology extension services can only be converted into actual adoption behaviors through farmers' internal cognitive and value judgment processes. This conversion process is realized through two mediating paths of technology cognition and value perception, forming a complete transmission chain of external intervention, internal motivation and behavioral response.

1. Mediating path of technology cognition

Technology cognition refers to farmers' objective understanding of technology attributes, operational requirements and application conditions, which serves as the prerequisite for technology adoption. One of the core functions of agricultural technology extension services is to transmit technical knowledge. The process of farmers receiving extension services is essentially the process of improving their technology cognition level. For complex technologies such as advanced agricultural technologies, farmers cannot obtain relevant knowledge independently through daily production experience, and extension services are the main channel for them to acquire technology cognition [22]. Agricultural technology extension services impart professional knowledge, including technical princi-

ples, operational specifications and supporting requirements, to farmers through technical training, on-site explanation and operation demonstration, which directly improves farmers' technology cognition level. When farmers fully grasp the core points of technology application, the complexity and uncertainty of the technology are greatly reduced, and their adoption willingness is significantly improved. This path reflects the conversion process from external knowledge input to internal cognitive ability and forms the cognitive basis for external interventions to exert their effects.

2. Mediating path of value perception

Value perception refers to farmers' subjective judgment of the expected benefits of technology adoption, which is the core motivation for technology adoption. As rational economic agents, farmers make technology adoption decisions mainly based on the trade-off between costs and benefits [23]. Agricultural technology extension services demonstrate the yield-increasing, cost-saving and environmental protection effects of technologies to farmers through demonstration field construction, income comparison calculation and typical case publicity, releasing clear value signals and improving farmers' expected benefits of technologies [21]. When farmers believe that the expected benefits of technology adoption are greater than the input costs, they will form a strong adoption motivation. This path reflects the conversion process from external value signals to internal motivation and forms the dynamic basis for external interventions to exert their effects. Based on this analysis, Research Hypothesis 2 is proposed.

Hypothesis 2. *Agricultural technology extension services indirectly promote farmers' technology adoption through two paths, namely improving technology cognition and enhancing value perception.*

2.2.3. Boundary Effect of Internal Perception: The Moderating Role of Risk Perception

The reason why risk perception plays a moderating role rather than a mediating role lies in the fundamental differences between its essential attributes, formation logic and functional modes and those of the previous two types of perception. From the perspective of essential attributes, risk perception is a stable psychological characteristic formed by farmers over a long period of time, representing an inherent attitude towards uncertainty, and is not directly affected by a single extension service. Mediating variables require that antecedent variables can significantly affect mediating variables, but agricultural technology extension services, as a single external intervention, cannot change farmers' risk preference in the short term, thus failing to meet the basic premise of mediating variables. From the perspective of formation logic, risk perception is not an output of external interventions, but an individual characteristic of farmers, independent of extension services. Farmers' risk perception is mainly determined by long-term factors such as their past production experience, wealth level and risk-bearing capacity, and has no direct causal relationship with whether they receive extension services. From the perspective of functional modes, risk perception is not an intermediate link of decision-making, but a boundary constraint condition for decision-making [24]. It does not directly determine whether farmers adopt technologies, but determines the intensity of the effects of external interventions and mediating variables. For farmers with high risk perception, decision-making is more cautious, and more external information and value incentives are required to make decisions, so the marginal effect of extension services is stronger [25]. For farmers with low risk perception, decision-making is more flexible, and the dependence on external information is lower, so the marginal effect of extension services is weaker.

This moderating effect reflects the interactive relationship between external interventions and internal perception characteristics. The effects of external interventions are not homogeneous, but depend on the inherent risk preference characteristics of farmers, and

the two form a complementary relationship. Based on this analysis, Research Hypothesis 3 is proposed.

Hypothesis 3. *Risk perception has a positive moderating effect on the effect of agricultural technology extension services.*

2.2.4. Heterogeneity of External Intervention Effects: Formation Mechanism of Regional Differences

As an external policy intervention, agricultural technology extension services are affected by external environmental factors, including local economic development level, extension system construction and farmers' endowment characteristics, presenting significant regional heterogeneity [15,26]. From the interactive logic of external intervention and internal perception, the formation of regional heterogeneity stems from differences in three dimensions.

The first dimension is the law of diminishing marginal effect. In developed regions with higher technical levels and smooth information circulation, farmers have a better foundation of technical cognition, and the information supplement effect of extension services diminishes marginally. In less developed regions, farmers have larger technical gaps, so the marginal effect of external information input is more significant [26].

The second dimension is the difference in extension resource allocation. The construction level of agricultural technology extension systems, the intensity of fund input and service precision vary across regions, which directly affect the quality and effect of external interventions. Major agricultural production regions usually receive more investment in extension resources, and the technical adaptability of services is stronger, leading to better extension effects [27].

The third dimension is the difference in internal demand. The proportion of agricultural income in total income, production and operation scale, and opportunity cost of labor of farmers in different regions are different, resulting in different intensities of internal demand for technologies. In regions with a higher proportion of agricultural income, farmers pay more attention to agricultural technologies and have higher responsiveness to extension services [15].

Based on the above analysis, Research Hypothesis 4 is proposed.

Hypothesis 4. *There is significant regional heterogeneity in the effect of agricultural technology extension services, and the extension effect in less developed major agricultural production regions is significantly higher than that in economically developed regions.*

3. Materials and Methods

3.1. Data Source

The data used in this study were obtained from a farm household survey conducted in Jiangsu Province from July to August 2025. A stratified random sampling strategy is employed to ensure sample representativeness. First, 3 representative counties (county-level cities or districts) are selected from southern, central and northern Jiangsu regions, considering the spatial heterogeneity of rice production in the province. Second, 2 to 3 townships are randomly chosen within each sampled county, followed by a random selection of 2 to 3 administrative villages in each township. Finally, 10 to 15 rice-growing households are randomly selected from each sampled village for face-to-face interviews. In total, 9 counties are covered in the survey.

All interviews are administered by well-trained enumerators who record responses on structured questionnaires during home visits. The questionnaire is designed to collect information across multiple dimensions: household demographic characteristics, agricul-

tural production practices, access to agricultural technology extension services, cognition and adoption of OFT for mechanically transplanted rice, social capital endowment, and cost–benefit structure of rice production. After eliminating invalid samples with missing key information or inconsistent responses, 675 valid observations are retained for empirical analysis. Among them, 198 samples are from southern Jiangsu (accounting for 29.3% of the total), 259 from central Jiangsu (38.4%), and 218 from northern Jiangsu (32.3%). The geographic distribution of the sample is highly consistent with the actual distribution of rice planting areas in Jiangsu Province, confirming the external validity of the sample.

3.2. Model Construction

Considering that the dependent variable, farmers' technology adoption behavior, is a binary dummy variable, this paper adopts the Probit model for benchmark regression analysis. The model is specified as follows:

$$Adopt_i = \beta_{01} + \beta_{11}Service_i + \gamma'_1Control_i + \varepsilon_{1i}, \quad (1)$$

where $Adopt_i$ represents the green fertilization technology adoption behavior of farmer i , $Service_i$ denotes the agricultural technology extension service variable, $Control_i$ is the vector of control variables, and ε_{1i} is the random error term. β_{11} is the core coefficient of interest in this paper, reflecting the marginal effect of agricultural technology extension services on farmers' technology adoption.

To address potential endogeneity arising from self-selection bias and reverse causality—farmers who are more inclined to adopt new technologies may also be more likely to seek out agricultural extension services—this study employs the Conditional Mixed Process (CMP) estimator combined with an instrumental variable approach. The CMP framework is particularly suited for recursive systems in which both the endogenous explanatory variable and the outcome variable are binary [28]. The framework jointly estimates the selection and outcome equations via a fully specified likelihood function, yielding consistent estimates under the assumption of joint normality of the error terms. The instrumental variables selected are traffic convenience and model farmer status. The CMP estimation includes two equations, and the specific model is specified as follows:

First-stage equation (instrumental variable regression):

$$\begin{cases} Service_i^* = \alpha_0 + \alpha_1 IV_{1i} + \alpha_2 IV_{2i} + \delta' Control_i + u_i \\ Service_i = 1[Service_i^* > 0] \end{cases}, \quad (2)$$

Second-stage equation (main regression equation):

$$\begin{cases} Adopt_i^* = \beta_0 + \beta_1 Service_i + \gamma' Control_i + \varepsilon_i \\ Adopt_i = 1[Adopt_i^* > 0] \end{cases}, \quad (3)$$

To examine the mediating mechanism through which agricultural technology extension services influence technology adoption, this paper adopts the stepwise regression method and the Bootstrap method to test the mediating effect, with the baseline model specified as Equation (1). Taking technical cognition as an example, the mediating effect model is specified as follows:

$$Cognition_i = \alpha_{02} + \alpha_{12}Service_i + \gamma'_2Control_i + \varepsilon_{2i}, \quad (4)$$

$$Adopt_i = \beta_{03} + \beta_{13}Service_i + \theta_3Cognition_i + \gamma'_3Control_i + \varepsilon_{3i} \quad (5)$$

where $Cognition_i$ is the mediating variable of technical cognition level, and θ_3 is the path coefficient of the mediating effect. If β_{11} , α_{12} and θ_3 are all significant, and the absolute value of β_{13} is smaller than that of β_{11} , a partial mediating effect exists. If β_{11} , α_{12} and θ_3 are all significant while β_{13} is not significant, a full mediating effect exists.

To examine the regional heterogeneity of the impact of agricultural technology extension services on technology adoption, this paper adopts the group regression method to conduct regression analysis on three subsamples of southern Jiangsu, central Jiangsu and northern Jiangsu, and judges the statistical significance of inter-regional differences through the coefficient difference test. All statistical analyses were performed using Stata 18.0 (StataCorp LLC, College Station, TX, USA).

3.3. Variable Selection

3.3.1. Dependent Variable

Table 1 presents the main variables involved in this study. The dependent variable is farmers' technology adoption behavior (Adopt). It is constructed based on the survey question "Have you used the rice mechanical transplanting with slow-release and mixed fertilizer one-time fertilization technology?" If a farmer answers "Yes", the variable takes the value of 1, indicating adoption of the technology; if the answer is "No", it takes the value of 0, indicating non-adoption.

Table 1. Variable definitions and summary statistics.

Variables	Definition	Mean	S.D.
Dependent variable			
Adopt	1 = Have adopted OFT, and 0 = Otherwise	0.39	0.49
Independent variable			
Service	1 = Have Received technology extension services, 0 = Otherwise	0.42	0.49
Control variables			
Health	Health status of respondent: 1 = Poor, 2 = Fair, and 3 = Healthy	2.82	0.40
Age	Age of respondent (years)	54.50	9.39
Education	Educational level of respondent (years)	9.38	3.28
Labor	Number of family labor force (persons)	3.17	1.24
Information	Whether the family has WIFI installed: 1 = Yes, and 0 = otherwise	0.97	0.16
Scale	Rice cultivation scale of the last year (mu)	418.75	745.97
Fragmentation	Rice cultivation scale per plot (mu/plot)	0.07	0.12
Fertility	Land fertility status (1–5 scale, higher = more fertile)	3.35	1.13
Region	1 = Southern Jiangsu, 2 = Central Jiangsu, 3 = Northern Jiangsu	2.03	0.79
Instrumental variables			
Traffic	Number of family cars (units)	1.35	0.98
Model	Whether it is a demonstration household: 1 = Yes, 0 = Otherwise	0.30	0.46
Mediating variables and moderating variables			
Cognition	Knowledge level of OFT	0.24	0.26
Value	Value assessment of OFT adoption effects	0.57	0.12
Risk	Risk perception for OFT adoption	0.38	0.27

3.3.2. Core Independent Variable

The core independent variable is the agricultural technology extension service (Service). It is a dummy variable constructed based on the survey question "Have you received agricultural technology extension services?" If a farmer answers "Yes", the variable takes the value of 1, indicating receipt of extension services; if the answer is "No", it takes the value of 0, indicating no receipt of extension services. In the subsequent robustness tests, the frequency of receiving agricultural technology extension services is used as an alternative explanatory variable.

3.3.3. Control Variables

The control variables selected in this study encompass three dimensions: household individual characteristics, household operation characteristics, and a regional dummy variable. The definitions and measurement methods are as follows.

Household individual characteristics include health status (Health), age (Age), and education level (Education), reflecting the physical health condition of the surveyed household head. The sample consists predominantly of middle-aged and older labor force (average age 54.5 years), with generally low educational attainment (average 9.38 years), which is consistent with the typical characteristics of aging and low-education agricultural practitioners in contemporary China.

Household operation characteristics include labor scale (Labor), information level (Information), planting scale (Scale), land fragmentation (Fragmentation), and land fertility status (Fertility). The labor scale is measured by the number of household members engaged in agricultural and related labor. Information level is proxied by whether the household has installed wireless internet, reflecting the household's information infrastructure conditions. Planting scale is defined as the rice planting area of the household in the previous year. Land fragmentation captures the degree of dispersion of a household's cultivated land parcels, measured by the average planting area per parcel. A smaller value indicates a higher degree of land fragmentation. As shown in Table 1, the sample households exhibit a high level of informatization (97% have WIFI installed), yet land fragmentation is severe (average parcel area is only 0.07 mu), reflecting the prevalent small-scale and fragmented operational pattern in major rice-producing regions. The standard deviation of planting scale is as large as 745.97 mu, indicating that the sample encompasses a wide range of operation types, from smallholders to large-scale specialized farms, suggesting good sample representativeness. Overall, the statistical distributions of the control variables are reasonable, providing a solid data foundation for subsequent empirical analysis.

To control for unobservable heterogeneity across regions, a regional dummy variable (Region) is introduced. Based on the three major regional divisions of Jiangsu Province, the variable is coded as follows: 1 = Southern Jiangsu, 2 = Central Jiangsu, and 3 = Northern Jiangsu.

3.3.4. Instrumental Variables

This study employs two instrumental variables: traffic convenience (Traffic), proxied by household automobile ownership, and model farmer status (Model), indicating whether a farmer has been designated as a demonstration household or demonstration base by the local agricultural technology extension system. The selection of these instruments is motivated by both theoretical considerations and the institutional features of China's agricultural technology extension system [15]. Traffic convenience is expected to affect farmers' access to extension services by lowering the physical and time costs of attending training sessions, participating in field demonstrations, and interacting with extension agents. Conditional on covariates, the residual variation in automobile ownership more plausibly captures household-level differences in travel convenience rather than systematic heterogeneity in agricultural productivity or technology preferences. Model farmer status, in turn, is a supply-side instrument rooted in the institutional design of China's agricultural extension system. Once designated, model farmers receive priority access to extension services, training materials, and technical guidance. The exclusion restriction requires that model farmer status influences technology adoption solely through its effect on access to agricultural extension services [29,30]. This assumption is not uncontestable: the selection criteria for model farmers—particularly farming experience and willingness to cooperate—may correlate with unobserved attributes such as innate farm-

ing ability or openness to innovation, which could directly affect adoption decisions. Nevertheless, after controlling for a rich set of observable household characteristics, the remaining variation in model farmer status is more likely attributable to quasi-random assignment by extension agencies than to unobserved adoption propensity. This identification strategy follows the spirit of the “selection on observables” approach [31], which evaluates the potential bias from unobservables by assessing the bias induced by observables [32,33].

3.3.5. Mediating Variables and Moderating Variables

The mediating variables are technological cognition level (Cognition) and technological value perception (Value). The moderate variable is technological risk perception (Risk).

Technological cognition level reflects the farmer’s subjective mastery of knowledge related to OFT. This variable characterizes the farmer’s depth of understanding of the new technology from the dimension of knowledge reserve and represents an important cognitive pathway through which agricultural extension services influence farmers’ adoption decisions. It is measured comprehensively based on nine technology-related knowledge questions in the questionnaire, covering key operational aspects such as fertilizer type identification, fertilization placement judgment, supporting seedling cultivation techniques, and supporting machinery types. Respondents are required to answer each of the nine questions. The average correct rate across these questions is used as the measure of technological cognition level. This indicator ranges from 0 to 1, with higher values indicating a higher level of technological cognition.

Technological value perception reflects the farmer’s subjective evaluation of the application effects of OFT. This variable characterizes the farmer’s judgment of the comprehensive value of the new technology from the dimension of benefit expectation, encompassing economic returns, production costs, and ecological environmental benefits. It is a key mediating variable through which agricultural extension services influence farmers’ adoption decisions via the pathway of benefit persuasion. It is measured based on five questions in the questionnaire regarding the evaluation of technology application effects, covering five dimensions: yield increase effect, cost-saving effect, income increase effect, fertilizer-saving effect, and environmental protection effect. Each question is measured using a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). The arithmetic mean of the scores from the five questions is taken as the raw score, which is then mapped to the 0–1 interval through min-max normalization. Value is the normalized technological value perception index, ranging from 0 to 1, with higher values indicating a more favorable evaluation of the technology’s value.

Technological risk perception reflects the farmer’s subjective level of concern regarding the potential risks associated with adopting OFT. This variable characterizes the farmer’s judgment of uncertainties related to the new technology from the dimension of risk concern, including yield fluctuations, operational errors, and sunk costs. In the theoretical framework, technological risk perception is designated as a moderating variable, rather than a mediating variable. That is, it moderates the strength of the influence of agricultural extension services on adoption decisions by forming a synergistic effect with these services. It is measured based on questions in the questionnaire regarding the farmer’s degree of concern about the risks of technology adoption, using a 5-point Likert scale (1 = not at all concerned, 5 = very concerned). The raw scores are mapped to the 0–1 interval through min-max normalization. Risk is the normalized technological risk perception index, ranging from 0 to 1, with higher values indicating a higher degree of perceived technological risk.

3.4. Sample Characteristics

Figure 2 presents the key statistical result characteristics of the core variables, highlighting the practical necessity of analysis from the dual dimensions of external intervention and internal perception.

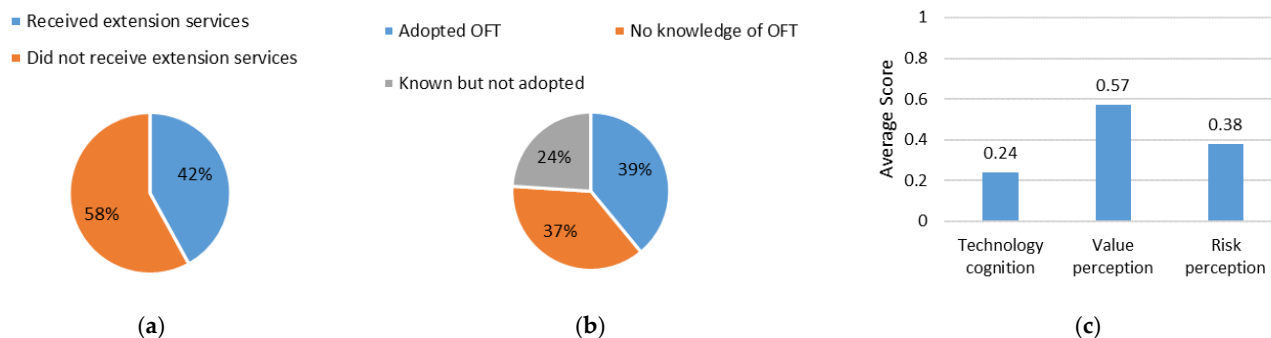


Figure 2. Key statistical characteristics of core variables. (a) Coverage of agricultural technology extension services; (b) Diffusion status distribution of OFT; (c) Comparison of farmers' perception scores.

First, the coverage of external intervention is insufficient. Only 42% of the sample farmers have received agricultural technology extension services related to OFT. More than half of the farmers have not been exposed to relevant extension services, indicating an obvious gap in technical information supply. Second, the degree of technology diffusion is low. Only 39% of farmers have adopted OFT, while 37% of farmers are completely unaware of the technology. The paradox of significant technological advantages but slow diffusion is prominent, reflecting the dual deficiencies of external intervention and internal perception. Third, there are large differences in farmers' internal perception levels. The average score of farmers' technical cognition is only 0.24, indicating that most farmers have a low level of understanding of OFT-related knowledge; the average score of value perception is 0.57, reflecting that farmers have a certain recognition of OFT's value, but there is still room for improvement. The average score of risk perception is 0.38, indicating that farmers' concern about OFT adoption risks is generally at a medium level.

The above characteristic facts show that the current promotion of OFT is simultaneously faced with the dual constraints of insufficient external intervention supply and low internal perception level. A single-dimensional perspective is insufficient to fully capture the complex internal mechanism of OFT adoption, underscoring the analytical necessity of a dual-dimensional framework. Accordingly, the following empirical analysis will systematically examine how external intervention and internal perception jointly influence farmers' OFT adoption behavior, and further explore the interaction effects and heterogeneous impacts between the two dimensions, so as to provide empirical evidence for breaking through the current diffusion bottleneck.

4. Results and Discussion

4.1. Main Regression Analysis

4.1.1. Baseline Regression

Table 2 reports the benchmark regression results of the impact of agricultural technology extension services on farmers' adoption of OFT. Model (1) only controls for regional dummy variables, while Model (2) adds all other control variables.

Table 2. Impact of agricultural technology extension service on OFT adoption.

Variables	Model (1)	Model (2)
Service	0.40 *** (0.01)	0.39 *** (0.01)
Health	—	0.02 (0.03)
Age	—	0.00 (0.00)
Education	—	−0.01 (0.00)
Labor	—	0.03 *** (0.01)
Information	—	0.13 (0.09)
Scale	—	0.00 (0.00)
Fragmentation	—	−0.17 (0.12)
Fertility	—	0.00 (0.01)
Central region	−0.21 *** (0.04)	−0.22 *** (0.04)
Northern region	−0.31 *** (0.04)	−0.29 *** (0.04)
Wald chi2	288.58 ***	310.02 ***
Pseudo R ²	0.43	0.45
N		675

Notes: (1) Standard errors in parentheses; (2) * < 0.10; ** < 0.05; *** < 0.01; (3) ‘—’ indicates the variable is not included in the corresponding stage regression.

As can be seen from Table 2, agricultural technology extension services have a significant positive impact on farmers’ technology adoption, and Hypothesis 1 is verified. In Model (1), which only controls for regional fixed effects, the average marginal effect of agricultural technology extension services is 0.40, indicating that each 1-unit increase in service supply increases the probability of farmers’ technology adoption by an average of 40 percentage points. In Model (2), which includes all control variables, the marginal effect of agricultural technology extension services decreases slightly to 0.39, still with significant economic significance, indicating that agricultural technology extension services are the core driving factor for promoting farmers’ adoption of green fertilization technologies.

The results of regional dummy variables show that the probability of technology adoption by farmers in southern Jiangsu is significantly higher than that in central Jiangsu and northern Jiangsu, which initially verifies the existence of differences in technology adoption among regions, and Hypothesis 4 is preliminarily confirmed. Among the control variables, only labor scale shows a significant positive impact, while other variables fail to pass the significance test, indicating that the promotion of the slow-release mixed one-time fertilization technology for rice mechanical transplanting has the characteristic of universality, is not obviously constrained by farmers’ individual endowments and cultivated land resource conditions, and has the foundation for large-scale promotion and implementation.

4.1.2. Endogeneity Test

Considering the possible endogeneity problems, such as two-way causality and selection bias, between agricultural technology extension services and technology adoption, this paper adopts the Conditional Mixed Process (CMP) estimation method for instrumental variable regression, and selects transportation convenience and whether the household is a demonstration household as instrumental variables. The regression results are presented in Table 3.

Table 3. Endogeneity test of the impact of agricultural technology extension on OFT adoption.

Variables	CMP	
	Stage 1	Stage 2
Service	—	2.74 *** (0.15)

Traffic	0.28 *** (0.05)	—
Model	0.34 *** (0.11)	—
atanhrho_12	−0.86 *** (0.43)	—
Wald chi2	570.61 ***	
N	675	

Notes: (1) Standard errors in parentheses; (2) * < 0.10; ** < 0.05; *** < 0.01; (3) ‘—’ indicates the variable is not included in the corresponding stage regression; (4) All control variables are controlled.

First-stage estimates indicate that both transportation convenience and model farmer status have a statistically significant positive effect on farmers’ access to agricultural extension services. The joint F-statistic for the instruments is 27.34, well exceeding the conventional threshold for weak instrument tests [34], confirming that the relevance condition is satisfied.

Regarding the exclusion restriction, the case for transportation convenience is relatively straightforward. Lower travel costs facilitate farmers’ participation in extension activities, and transportation conditions primarily influence technology adoption indirectly through improved access to extension services, rather than directly determining farmers’ fertilizer application choices. The validity of model farmer status as an instrument, however, warrants more careful scrutiny. Within China’s agricultural technology extension system, model farmers are prioritized recipients of extension resources, establishing an institutional link between this status and service access. Nevertheless, the selection of model farmers may be based on characteristics—such as farming ability, social networks, or openness to innovation—that are also correlated with technology adoption, thereby posing a potential threat to the exclusion restriction. To mitigate this concern, the model controls for a comprehensive set of observable characteristics, including health status, educational attainment, labor endowment, farm size, and land fertility. Furthermore, following a sensitivity analysis approach, the estimated coefficient remains statistically significant even if unobservable factors explain substantially more of the outcome variance than the observable controls [35].

In summary, the estimated atanhrho_12 is statistically significant, confirming the presence of endogeneity and justifying the use of the CMP model. After correcting for endogeneity, the coefficient of agricultural extension services on OFT adoption is 2.74 ($p < 0.01$), providing further support for Hypothesis 1. The CMP estimate is substantially larger than the baseline Probit marginal effect (0.39). This discrepancy is consistent with the interpretation that the instrumental variable estimator captures the local average treatment effect (LATE) for the subpopulation of compliers, and may also reflect correction for attenuation bias arising from measurement error in the extension service variable [36].

4.2. Mechanism Analysis

To test the mediating mechanism of agricultural technology extension services affecting technology adoption, this paper takes technical cognition, perceived technical value and perceived technical risk as mediating variables to conduct mediating effect tests. Table 4 reports the test results of the stepwise regression method.

Table 4. Mediating effect test of the impact of agricultural technology extension on OFT adoption.

Variables	Technical Cognition		Value Perception		Risk Perception	
	Equation (4)	Equation (5)	Equation (4)	Equation (5)	Equation (4)	Equation (5)
Service	0.31 *** (0.02)	1.26 *** (0.16)	0.09 *** (0.01)	1.75 *** (0.14)	−0.01 (0.02)	1.94 *** (0.13)
Cognition	—	3.10 *** (0.42)	—	—	—	—
Value	—	—	—	3.17 *** (0.61)	—	—
Risk	—	—	—	—	—	0.66 *** (0.22)

Constant	0.16 (0.10)	−2.15 ** (0.86)	0.42 *** (0.05)	−3.06 *** (0.93)	0.50 *** (0.14)	−1.91 ** (0.86)
R ²	0.51	0.55	0.21	0.49	0.01	0.46
N	675					

Notes: (1) Standard errors in parentheses; (2) * < 0.10; ** < 0.05; *** < 0.01; (3) ‘—’ indicates the variable is not included in the corresponding stage regression; (4) All control variables are controlled.

As shown in Table 4, the mediating paths of technological cognition and value perception are validated, while the mediating effect of risk perception is not statistically significant. Hypothesis 2 is therefore supported. Specifically, the impacts of agricultural technology extension services on both technological cognition and value perception are statistically significant at the 1% level, satisfying the criterion that the independent variable exerts a significant effect on the mediating variables. After adding the mediating variables, the impact coefficients of agricultural technology extension services on technology adoption decrease from 1.91 in the baseline regression to 1.26 and 1.75, but still remain significant at the 1% level. Meanwhile, the impact coefficients of technical cognition and perceived value on technology adoption are significant at the 1% level, satisfying the conditions that the mediating variable significantly affects the dependent variable, and the coefficient of the independent variable decreases, indicating that technical cognition and perceived value have partial mediating effects. In the mediating effect test of perceived risk, the impact coefficient of agricultural technology extension services on perceived risk is not significant, so the mediating effect of perceived risk is not established.

To avoid the assumption limitation of the Sobel test on the normal distribution of indirect effects, the Bootstrap test further verifies the robustness of the mediating effect by repeating 5000 samplings, and the results are shown in Table 5:

Table 5. Bootstrap Test of Mediating Effects.

Variables	Effect Type	Coefficient	95% Confidence Interval	Proportion
Cognition	Indirect	0.16 *** (0.05)	[0.07,0.25]	34.5%
	Direct	0.43 *** (0.06)	[0.31,0.55]	
	Total	0.59 *** (0.04)	[0.51,0.67]	
Value	Indirect	0.08 *** (0.02)	[0.04,0.11]	13.1%
	Direct	0.50 *** (0.04)	[0.42,0.58]	
	Total	0.57 *** (0.04)	[0.50,0.65]	
Risk	Indirect	−0.01 (0.01)	[−0.03,0.02]	—
	Direct	0.57 *** (0.04)	[0.50,0.64]	
	Total	0.56 *** (0.04)	[0.49,0.63]	

Notes: (1) Standard errors in parentheses; (2) * < 0.10; ** < 0.05; *** < 0.01; (3) ‘—’ indicates the variable is not included in the corresponding stage regression.

The total effects of the three models are stable between 0.56 and 0.59, verifying the core promoting effect of agricultural technology extension services on technology adoption, and the effect structures of different mediating variables show significant differences.

The mediating effect of technical cognition accounts for more than one-third, which is the most important transmission path of agricultural technology extension services. Through technical training, on-site guidance, demonstration and display, agricultural technology extension service organizations help farmers understand the operation methods, application conditions and technical key points of new technologies, eliminate information asymmetry, and fundamentally reduce the threshold of technology adoption for farmers. The potential results show that the improvement of the technical cognition level can independently drive the increase in farmers’ adoption rate by 34.5 percentage points, which is the core intermediate factor driving adoption decisions.

The mediating effect of perceived value accounts for about 13%, which is the secondary transmission path of agricultural technology extension services. On the basis of farmers' understanding of technology, extension services strengthen farmers' recognition of the effects of technology in increasing production, reducing costs and increasing income through income calculation, case explanation and effect display, so as to further improve farmers' willingness to adopt. However, compared with technical cognition, the role of perceived value is relatively limited, reflecting that in the promotion scenario of rice green fertilization technology, farmers already have relatively stable expectations of technical value, and the marginal improvement space of extension services is small.

The mediating effect of perceived risk is not significant, and the 95% confidence interval contains 0, indicating that current agricultural technology extension services do not affect adoption decisions by reducing farmers' perceived risk. The potential results show that the level of perceived risk has almost no impact on farmers' adoption rate. This result reflects that farmers' adoption decisions are mainly constrained by resource constraints rather than risk preference constraints, and the direct empowerment measures, such as material support and technical guidance of current extension services, have covered the impact of risk factors.

Since the mediating effect of perceived risk is not significant, this study further constructs an interaction effect model to test whether perceived risk acts as a moderating variable to affect the effect of agricultural technology extension services. The interaction term between agricultural technology extension services and perceived risk is introduced into the baseline regression model, and the heteroscedasticity robust standard error is used for estimation. The regression results are shown in Table 6.

Table 6. Test of the Moderating Effect of Perceived Risk.

Variables	Moderating Effect
Service	2.00 *** (0.14)
Risk	1.04 *** (0.25)
Service × Risk	2.80 *** (0.57)
Health	0.03 (0.16)
Age	−0.01 (0.01)
Education	−0.03 (0.02)
Labor	0.14 *** (0.05)
Information	0.68 (0.43)
Scale	0.01 (0.01)
Fragmentation	−1.16 * (0.12)
Fertility	−0.01 (0.06)
Central region	−0.89 *** (0.16)
Northern region	−1.17 *** (0.17)
Wald chi2	303.84 ***
Pseudo R ²	0.48
N	675

Notes: (1) Standard errors in parentheses; (2) * < 0.10; ** < 0.05; *** < 0.01.

The regression results show that the coefficient of the interaction term between agricultural technology extension services and perceived risk is 2.80, which is significant at the 1% level. This indicates that risk perception exerts a significant positive moderating effect on the impact of agricultural technology extension services, thus Hypothesis 3 is supported. First, the main effects of the model are stable. The main effect coefficient of agricultural technology extension services is 2.004, and the main effect coefficient of perceived risk is 1.039, both of which are consistent with the baseline regression results, indi-

cating that both have independent promoting effects on technology adoption. Second, the synergistic effect of the model is significant. The coefficient of the interaction term is significantly positive, indicating that there is a complementary relationship between agricultural technology extension services and perceived risk. The higher the perceived risk, the stronger the promoting effect of agricultural technology extension services. The marginal effect calculation shows that for farmers with low perceived risk, the marginal improvement effect of extension services on adoption probability is 42.3 percentage points; for farmers with high perceived risk, the marginal improvement effect of extension services can reach 78.6 percentage points, which is 1.86 times that of the former. Finally, the transmission mechanism of the model is clear. This result explains the reason why the mediating effect of perceived risk is not established; that is, perceived risk does not act as a mediating variable to transmit the impact of extension services, but acts as a moderating variable to form a synergistic effect with extension services, and the two jointly affect farmers' technology adoption decisions. Extension services cannot directly change farmers' perceived risk level, but can complement farmers' existing perceived risk characteristics and amplify the policy effect on farmers with a high-risk preference.

4.3. Heterogeneity Analysis

To further examine whether there exists regional heterogeneity in the impact of agricultural technology extension services on farmers' adoption of new technologies, this study divides the full sample into three sub-samples corresponding to the southern region, central region and northern region, and conducts Probit regression on each sub-sample. The Z-test for between-group coefficient difference is employed to verify the statistical significance of the difference in the estimated coefficients of extension service supply across regions.

As shown in the estimation results of Table 7, the heterogeneity of extension effects across the three regions presents clear hierarchical characteristics. The difference between central and northern Jiangsu is statistically significant: the coefficient difference in extension services between the two groups is -0.71 , which is significant at the 5% level, indicating that the effect of agricultural technology extension services in northern Jiangsu is significantly higher than that in central Jiangsu. No significant difference is found between southern Jiangsu and the other two regions. Although the coefficient shows that the extension effect in northern Jiangsu is slightly higher than that in southern Jiangsu, this difference fails to pass the significance test, suggesting that the extension effects of the two regions are generally at the same level. Overall, the extension effect in less developed major agricultural production regions is significantly higher than that in economically developed regions, which verifies Hypothesis 4.

Table 7. Heterogeneity test results by region.

Group	Coefficient Difference	Z-Value
Southern vs. Central	0.30	0.97
Southern vs. Northern	-0.40	-1.07
Central vs. Northern	-0.71^{***}	-2.00

Notes: (1) $*$ < 0.10 ; $**$ < 0.05 ; $***$ < 0.01 ; (2) the between-group coefficient difference is calculated as the estimated coefficient of extension service supply in the former region minus that in the latter region. A negative sign indicates that the coefficient of the latter region is larger.

This result is highly consistent with the regional characteristics of agricultural development in Jiangsu Province, which can be explained by three dimensions. First, the law of diminishing marginal effect of technical extension services applies. The overall agricultural technology level in central Jiangsu is higher than that in northern Jiangsu, and farm-

ers have a better cognitive foundation for new technologies such as one-time fertilization, leaving relatively limited room for marginal improvement of extension services. In contrast, traditional planting modes account for a higher proportion in northern Jiangsu, where there is a larger technology gap. Extension services can effectively fill the information gap, leading to more significant marginal effects. Second, there are differences in the precision of extension resources. As the core agricultural production region in Jiangsu Province, northern Jiangsu has received preferential allocation of provincial-level agricultural technology extension resources in recent years. This has fostered a more well-established extension system, more targeted service delivery, and stronger technical adaptability tailored to the needs of major rice-producing areas, which collectively explain its better extension performance compared with central Jiangsu. Third, differences exist in farmers' willingness to adopt. Farmers in northern Jiangsu have a higher proportion of agricultural income, more urgent demand for new technologies, and higher acceptance and responsiveness to extension services. In central Jiangsu, where the secondary and tertiary industries are more developed, farmers have a higher proportion of non-agricultural income and pay relatively less attention to agricultural technologies, which weakens the effect of extension services [26].

4.4. Robustness Tests

To ensure the reliability of the research conclusions, this study employs two approaches for robustness checks. First, the core explanatory variable is replaced from access to agricultural technology extension services, a binary dummy variable, to frequency of agricultural technology extension services, a continuous variable, and Probit regression is re-conducted with average marginal effects calculated accordingly. Second, the Probit model used in the baseline regression is substituted with a Logit model for re-estimation. The results are presented in Table 8.

Table 8. Robustness tests.

Variables	Probit Model	Logit Model
Service-frequency	0.10 ** (0.01)	—
Service	—	0.37 *** (0.01)
Central region	−0.27 *** (0.04)	−0.22 *** (0.04)
Northern region	−0.34 *** (0.04)	−0.29 *** (0.04)
Wald chi2	168.71 ***	236.19 ***
Pseudo R ²	0.42	0.45
N	675	

Notes: (1) Standard errors in parentheses; (2) * < 0.10; ** < 0.05; *** < 0.01; (3) '—' indicates the variable is not included in the corresponding stage regression; (4) All control variables are controlled.

After replacing the core explanatory variable, the coefficient of extension service frequency is significantly positive at the 1% level, with a marginal effect of 0.10. This indicates that each additional extension service increases the probability of farmers' technology adoption by an average of 10.3 percentage points, which is highly consistent with the baseline regression conclusions and verifies the robustness of the core findings. This result also implies that agricultural technology extension should not only achieve service coverage but also ensure a certain level of service intensity.

The re-estimation results using the Logit model show that the coefficient of agricultural technology extension services remains significantly positive at the 1% level. The average marginal effect indicates that the marginal promotion effect of extension services on technology adoption probability is 37.2 percentage points, which is basically consistent

with the baseline regression results. This further validates the stability of the core conclusions and eliminates the interference of model specification bias.

The results of both robustness checks demonstrate that the promotion effect of agricultural technology extension services on farmers' adoption of new technologies is highly robust, which is not affected by the measurement method of core variables or the choice of regression models, confirming the reliability of the core conclusions [36].

5. Conclusions and Policy Recommendations

5.1. Conclusions

Based on micro-survey data of 675 rice-growing households in Jiangsu Province, this study constructs a two-dimensional analytical framework encompassing external intervention, internal motivation, and behavioral response, and systematically examines the impact of agricultural technology extension services, a typical external intervention, on the adoption of one-time fertilization technology and its underlying mechanisms.

- External intervention is the core exogenous driving force for farmers to adopt advanced agricultural technologies. The empirical results show that after controlling for other factors, the probability of technology adoption for farmers who have access to agricultural technology extension services increases by an average of 39 percentage points. This effect remains highly robust after using the instrumental variable method to alleviate endogeneity problems, replacing the core explanatory variable with extension service frequency, and changing the regression model to the Logit model. This fully verifies the critical role of the government-led agricultural technology extension system in solving the market failure of advanced technology diffusion and breaking through the “last mile” of technology implementation, and also indicates that the current promotion of advanced agricultural technologies is still constrained by a significantly insufficient information supply.
- The transmission of external intervention effects depends on the mediating and moderating effects of internal perceptions. The mediating effect test shows that technology cognition and value perception are two significant mediating paths. Agricultural technology extension services improve farmers' understanding of technologies through technical training, demonstration and display, and strengthen farmers' recognition of the value of technologies in increasing yield and reducing costs. Both of them jointly constitute the core channel for the transformation of external intervention into adoption behavior. The mediating effect of risk perception is not valid, but there is a significant positive moderating effect. Agricultural technology extension services and risk perception show a complementary relationship: the higher the risk perception of farmers, the stronger the promotion effect of extension services. This indicates that external intervention can effectively match the information needs of farmers with high-risk preferences and amplify policy effects.
- There is significant regional heterogeneity in the effect of external intervention, which is the result of the joint action of local extension resource endowment and farmers' internal demand. The sub-sample regression results show that the extension effect in less developed major agricultural production regions is significantly higher than that in economically developed regions. Specifically, the extension effect in northern Jiangsu is significantly higher than that in central Jiangsu, while the difference between southern Jiangsu and the other two regions is not significant. This heterogeneity characteristic can be jointly explained by the law of diminishing marginal effect, disparities in extension resource allocation, and differences in farmer demand. As a major agricultural production region, Northern Jiangsu has a larger technology gap, higher investment intensity of extension resources, a higher share of agricultural in-

come in farmers' total income, and more urgent technology demand. These factors collectively contribute to a more significant marginal effect of extension services in the region.

5.2. Policy Recommendations

Based on the above research conclusions, the following policy implications are proposed to optimize the agricultural technology extension service system and accelerate the diffusion of advanced agricultural technologies.

- The government should continuously strengthen the supply of external interventions and pursue the dual goals of wide coverage and high intensity of extension services in a coordinated manner. On the other hand, it is necessary to ensure the intensity of extension services, carry out multiple rounds of targeted extension for key farmers, and establish a full-process service mechanism covering training, demonstration, and follow-up to maximize the marginal benefit of extension services. Meanwhile, extension service approaches should be innovated, with multiple methods such as on-site demonstration, technical training, and follow-up guidance comprehensively adopted to improve the practical effectiveness of extension services.
- Extension institutions should optimize the content design of extension services and accurately unblock the transmission path of internal perception. For the technology cognition transmission path, a hierarchical and classified technical training system should be improved, focusing on explaining technical principles, operation specifications and supporting management requirements, to help farmers quickly master the key knowledge of technology application and reduce the cost of technology learning. For the value perception transmission path, a sound visual display mechanism for technical effects should be established, and the yield-increasing, cost-saving and environmental protection effects of technologies should be intuitively presented through the construction of demonstration fields, publicity of typical cases, comparison of input and income and other ways, to enhance farmers' recognition of the practical value of technologies.
- Local governments should implement differentiated extension strategies to fully match farmers' risk preference characteristics and regional heterogeneous demands. For farmers with higher risk preferences, the technology adoption rate can be rapidly improved through conventional extension services. For risk-averse farmers, supporting measures such as agricultural insurance, technical application risk guarantee and paired driving by demonstration households should be provided to reduce their risk concerns about technology adoption. In terms of regional resource allocation, extension resources should continue to be tilted towards less developed major agricultural production areas such as northern Jiangsu to consolidate their advantages in extension effects. For regions with weak extension effects, such as central Jiangsu, the key direction of extension services should be adjusted, highlighting the labor-saving and cost-saving advantages of technologies, to match the demand characteristics of farmers with a high proportion of non-agricultural income.

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Abbreviations

The following abbreviations are used in this manuscript:

OFT One-time Fertilization Technology for Mechanized Transplanting Rice

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