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# The Impact of Environmental Regulation and Technical Cognition on Farmers' Adoption of Safety Agro-Utilization of Heavy Metal-Contaminated Farmland Soil

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**Abstract:** Regarding the large-scale heavy metal pollution in farmland, China has innovatively explored a farming measure governance approach of "production while repairing". However, due to farmers' difficulty breaking through conventional planting habits, the governance effects need to be more sustainable. Based on 447 survey data of farmers in 14 cadmium-polluted counties (cities) in Hunan Province, this paper uses the Bootstrap method to explore the impact of environmental regulation, technical cognition, and self-efficacy on farmers' adoption of "variety–irrigation–pH" (VIP) technology. The results show the following: (1) Environmental regulation can effectively improve farmers' adoption of VIP technology, and different types of regulation are classified as guidance regulation, constraint regulation, and incentive regulation according to the size of their impact. (2) Technical cognition mediates the environmental regulation process influencing farmers' adoption. (3) In the process of environmental regulation influencing farmers' adoption of irrigation and pH through technical cognition, the moderating effect of self-efficacy was positive. Enhance the strategic planning of environmental regulation, bolster technological research and development efforts, and nurture innovative agricultural entities that can promote the adoption of VIP technology. The results have practical significance for further guiding farmers to participate in treating heavy metal pollution.

**Keywords:** environmental regulation; individual cognition; self-efficacy; heavy metal-contaminated farmland soil; stimulus–organism–response theory



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## 1. Introduction

Soil heavy metal pollution can lead to excessive levels of heavy metals in crops, which migrate through the food chain into the human body, posing a threat to health [1]. In China, up to 19.4% of the farmland has been contaminated [2]. Notably, the areas affected by soil heavy metal pollution in China overlap significantly with major grain production regions [3]. Rice, a staple food for the Chinese people, contributes to 55.8% of the cadmium intake in the bodies of Chinese residents [4]. Surveys have revealed that more than 10% of rice samples exceed the national cadmium content standard, with the problem being particularly severe in southern regions [5]. Heavy metal pollution annually reduces grain production by 10 million tons, with up to 12 million tons of contaminated grain, resulting in significant economic losses exceeding USD 2.76 billion [6]. This pollution has become a critical obstacle to China's food security and sustainable agricultural development.

To mitigate food security risks and enhance the sustainability of farmland utilization, the Chinese government has embarked on several pivotal scientific research projects and governance pilots. These include the "Research and Demonstration of Safe Utilization Technology for Farmland with Excessive Heavy Metals" and the "Pilot Project for the Restoration of Heavy Metal-Contaminated Cultivated Land and Crop Planting Structure

Adjustment in Hunan Province" [7]. Aiming at the problem of excessive cadmium in rice caused by heavy metal pollution in cultivated land, Chinese scientists have developed remediation techniques for heavy metal pollution in farmland and safe agricultural utilization strategies tailored to China's specific conditions, formulating a comprehensive response plan suitable for large-scale demonstration and promotion [8]. Notably, the "variety–irrigation–pH" (VIP) technology, pioneered by the Institute of Subtropical Agriculture, Chinese Academy of Sciences (ISA) in 2013, was recognized by the Ministry of Agriculture and Ministry of Finance as a crucial technology for managing and safely utilizing cadmium-contaminated farmland [9]. Since 2014, this technology has been implemented in pilot projects within Changsha, Zhuzhou, and Xiangtan in Hunan Province, and its application has subsequently expanded to encompass other heavy metal-polluted cultivated areas across the country. Subsequently, the state enacted the Soil Pollution Prevention and Control Action Plan along with the Soil Pollution Prevention and Control Law. These legislations serve to steer and oversee the utilization of cultivated land, enhance the underlying principles of environmental regulations about managing heavy metal pollution in agricultural soil, and refine policy objectives and prerequisites. The aim is to mitigate the conflict between agricultural production and the ecological preservation of farmland. However, the survey revealed a notable discrepancy between farmers' high willingness and adoption of VIP technology [10]. The depth and breadth of technology application fell short of expectations [11], and a significant gap existed between the intended policy effect and the achieved environmental regulation goals [12]. Consequently, it is imperative to investigate the impact and mechanisms of environmental regulations on farmers' technology adoption behavior, and to identify the obstacles hindering farmers' sustainable adoption of VIP technology.

Farmers, as the direct users of cultivated land, play a pivotal role in determining the effectiveness of pollution control measures. Both external policy stimuli and internal technical cognition significantly influence their behavior in adopting technological solutions [13,14]. Environmental regulation is vital in addressing the challenges posed by cultivated land protection externalities [15]. Governments can facilitate farmers' technology adoption by providing informational, material, and technical support, and imposing behavioral constraints through regulatory policies [16,17]. However, research indicates that a top-down approach to environmental regulation may fail to achieve its objectives if it overlooks farmers' technical needs and psychological cognition [18,19]. This can lead to "relativity system failure" [20], undermining the effectiveness of regulatory measures. The technology diffusion theory emphasizes technical cognition's centrality in disseminating new technologies [21]. Divergent technical cognition leads to varying biases in technology choice [22]. Previous studies have explored farmers' technical cognition in multiple dimensions, including technical characteristics, effects, and benefits. They have found that positive technical cognition is a significant driver of farmers' technology adoption behavior [23]. For instance, a strong perception of a technology's usefulness and ease of use and a high perception of its benefits increase the likelihood of farmers adopting it. Conversely, farmers' perceptions of the technology's cost and risk can significantly hinder its adoption [24–26]. Simultaneously, scholars have recognized the role of self-efficacy in facilitating the transition from technical cognition to actual adoption [27].

Previous studies have conducted more in-depth research on the impact of government intervention and technical cognition on farmers' technology adoption behavior. Since self-efficacy refers to an individual's belief and confidence in completing a task or achieving a goal [28], it can affect the transition between individual cognition and behavior [29,30]. Therefore, in the treatment of heavy metal-contaminated farmland, whether self-efficacy can deepen farmers' technical cognition and whether technical cognition will enhance farmers' compliance with environmental regulations remains to be further discussed. Therefore, it is necessary to integrate self-efficacy, technical cognition, and environmental regulations into a unified analytical framework to explore ways to improve farmers' technology adoption behavior. Based on this, this article takes VIP technology for treating heavy metal-contaminated farmland as an example. Using survey data from 447 farmers in 14 counties in Hunan Province, China, and drawing on the Stimulus–Organism–Response (S–O–R) theory, this paper constructs the analytical framework "Environmental Regulation-Technical Cognition-Technology Adoption Behavior". It delves into the relationship between environmental regulation, technical cognition, and self-efficacy, and their impact on farmers' adoption of VIP technology. This research aims to provide new ideas and insights for improving the effectiveness of heavy metal-contaminated farmland management and safe utilization.

## 2. Theoretical Analysis and Research Hypotheses

### *2.1. The Impact of Environmental Regulations on the Adoption Behavior of VIP Technologies by Farmers*

The S–O–R theory proposes that individuals react to external environmental stimuli with cognitive and emotional changes, leading to approach or avoidance behaviors [31]. Environmental regulation is a crucial aspect of external stimuli and can modulate farmers' agricultural practices through guidance, incentives, and constraints. In China's agricultural market, a macro-environment of "high quality with high price" has not yet formed [32], making it challenging to monetize the significant positive externalities of VIP technology through market mechanisms [33]. As a result, rational farmers tend to stick to their traditional farming practices. According to the theory of externalities [34], the government can stimulate farmers to adopt safe utilization technologies beneficial to food security by subsidizing those who adopt VIP technology, thus reducing the cost of technology adoption and aligning farmers' production behaviors with social benefits. For instance, a strong perception of a technology's usefulness, ease of use, and benefits increases the likelihood of farmers adopting it [35], reducing the uncertainty of technology adoption and farmers' concerns about encouraging technology adoption. Additionally, government supervision can restrain farmers' "passive" land utilization behaviors [36]. By imposing fines and criticism, the government conveys the importance of protecting cultivated land ecology to farmers, making them aware of the significance and seriousness of adopting eco-friendly agricultural technologies and prompting them to align with regulatory goals. Based on this, this study proposes the research hypothesis:

**Hypothesis 1.** *The three types of environmental regulation—guidance, incentives, and constraints—can promote farmers' adoption of VIP technologies.*

### *2.2. The Mediating Role of Technical Cognition*

The S–O–R theory suggests that individuals respond behaviorally to external stimuli, and their psychological cognition is a mediating factor in this process. In this paper, the organism (O) in the theoretical model is embodied as technical cognition, representing farmers' subjective evaluation of agricultural technology based on others' experiences and personal practical experiences [37]. Farmers disadvantaged in technological information may form incomplete subjective perceptions of complex new technologies, inhibiting their technology adoption behavior. The government can enhance farmers' information reception and perception of technology's ease of use and usefulness and lower the barrier to technology use through regulatory "traction", such as technical training and subsidy incentives, and supervisory "propulsion", such as punishments [18]. This can reshape farmers' perceptions of the costs, benefits, and risks associated with VIP technology, making them more willing to respond to regulatory requirements and actively implement it. Therefore, this study proposes the research hypothesis:

**Hypothesis 2.** *There is an interactive effect between technical cognition and environmental regulations, and technical cognition plays an intermediary role in promoting farmers to adopt VIP technologies by regulatory requirements.*

### 2.3. The Moderating Role of Self-Efficacy

In the S–O–R theory, the transition from technical cognition to technology adoption relies on organismic capability [38]. Organismic capability regulates the intensity of the S–O–R process by triggering cognitive schemas [39], ultimately determining the extent to which the behavior can be completed. Organismic capability is often measured by self-efficacy [40]. Farmers with high self-efficacy tend to be optimistic about expected benefits, perceive lower risks in adopting new technologies, and have more confidence in controlling their actions' implementation process and outcomes, thus being more inclined to put them into practice [41,42]. On the one hand, farmers with high self-efficacy possess more social resources and sales channels, reducing the asymmetry of market information to some extent and increasing the likelihood of achieving high quality and high prices for agricultural products. On the other hand, farmers with high self-efficacy have advantages in technology, labor, and capital investment, implement technical procedures more standardly, and can overcome difficulties encountered in implementing new technologies by learning from experiences and reducing the risk of improper technology application [43]. Conversely, farmers' doubts about their abilities can limit their cognitive level, leading them to abandon adopting technologies perceived as beyond their capabilities [44]. Therefore, heterogeneity in self-efficacy can influence the effect of technical cognition on VIP technology adoption behavior. On this basis, this paper proposes the research hypothesis:

**Hypothesis 3.** *Self-efficacy moderates the relationship between technological knowledge and farmers' VIP technology adoption behavior.*

Following a comprehensive analysis, this paper uses the S–O–R theory to construct a decision-making model for farmers' VIP technology adoption behavior, starting from environmental regulations, technical cognition, and self-efficacy. Please refer to Figure 1 for details. The model unfolds along two logical lines: firstly, it aims to explain the transmission mechanism through which different environmental regulations affect farmers' technology adoption behavior via technical cognition. Secondly, it tests whether self-efficacy has a moderating effect in the process where environmental regulations influence farmers' technology adoption behavior through technical cognition.

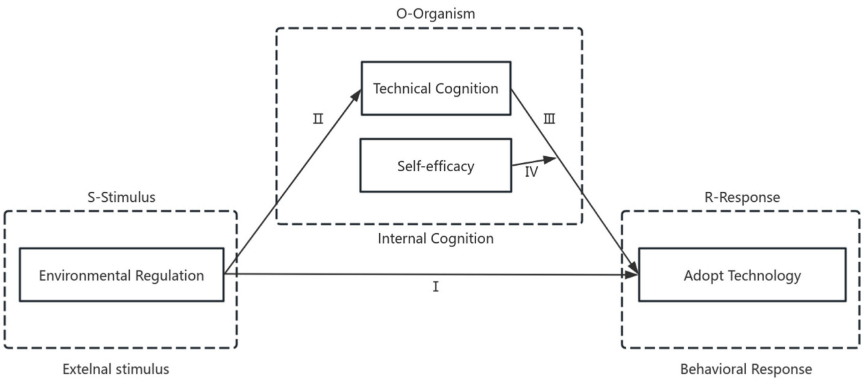


**Figure 1.** Analysis framework of S-O-R theory for farmers' technology adoption.

## 3. Research Methodology

### 3.1. Data Sources

The data presented in this study were collected as part of the "Safe Utilization of Polluted Farmland" project in Hunan Province, China, from 2022 to 2023. Fourteen counties (cities) contaminated with cadmium were carefully selected from various regions, encompassing Hengyang City (2 counties), Chenzhou City (2 counties), Yongzhou City (2 counties), Yiyang City (1 county), Huaihua City (1 county), Zhangjiajie City (2 counties), and Xiangxi Prefecture (4 counties), for an in-depth study on the remediation and safe utilization of polluted farmland. From each county, 1–2 project villages were picked, considering criteria like farmland size, policy enforcement, and farmer engagement, and the survey was ultimately conducted on 20 sample villages. Within each village, 20–25 households were randomly chosen for interviews and questionnaires. The study aimed to collect comprehensive data on household heads' demographics, family dynamics, adherence to environmental policies, farmers' technical proficiency, self-efficacy, and their technology adoption. A total of 490 farmers took part in the survey, resulting in 490 questionnaires being filled out. Post-screening, 447 valid questionnaires were retained, reflecting a 91.2% validity rate.

The data used in this study are all from the above 447 surveys. The basic characteristics of the interviewed farmers are shown in Table 1. Most of the respondents are male, accounting for 71.59%, while females only account for 28.41%; the majority are over 50 years old, accounting for 71.36%; the level of education is generally low, with 69.57% of respondents having only junior high school education or below; most of them are individual farmers, and the rice planting scale is generally small, with 66.89% of farmers planting an area of less than 0.34 hectare; household agricultural income is not high, with 68.23% of interviewed farmers having an annual household agricultural income of less than USD 2765.

**Table 1.** Descriptive statistics of sample farmers.

| Content of the Survey | Options | Frequency | Percentage |
|---|---|---|---|
| Gender | Woman | 127 | 28.41 |
| | Male | 320 | 71.59 |
| Age | 30 years old and under | 10 | 2.24 |
| | 31–40 years old | 37 | 8.28 |
| | 41–50 years old | 81 | 18.12 |
| | 51–60 years old | 175 | 39.15 |
| | 61 years old and over | 144 | 32.21 |
| Level of education | Illiteracy | 20 | 4.47 |
| | Primary school | 119 | 26.62 |
| | Middle school | 172 | 38.48 |
| | High school | 103 | 23.04 |
| | College and above | 33 | 7.38 |
| Type of business | Individual | 372 | 83.22 |
| | Large-scale grain farmers | 41 | 9.17 |
| | Cooperative | 34 | 7.61 |
| The scale of rice cultivation | Less than 0.2 hectare | 151 | 33.78 |
| | 0.2–0.34 hectare | 148 | 33.11 |
| | 0.34–0.47 hectare | 67 | 14.99 |
| | 0.47–0.67 hectare | 26 | 5.82 |
| | 0.67 hectares and above | 55 | 12.30 |
| Family income from agriculture | Less than USD 2765 | 305 | 68.23 |
| | USD 2765–5530 | 60 | 13.42 |
| | USD 5530–8295 | 7 | 1.57 |
| | USD 8295–11,060 | 14 | 3.13 |
| | USD 11,060 and above | 61 | 13.65 |

### *3.2. Variable Selection*

#### 3.2.1. Dependent Variable

Drawing upon the technical regulations outlined in the "Recommended Technology List for Safe Utilization, Treatment, and Restoration of Light to Moderate Polluted Cultivated Land (2019 Edition)" issued by the General Office of the Ministry of Agriculture and Rural Affairs of China, this study has identified the following questions as indicators of farmers' adoption of VIP technology: "Do farmers cultivate cadmium-low-accumulation varieties?" "Do they maintain a certain flooding depth during rice growth, draining and drying the field

7–10 days before harvest?" and "Do they evenly apply sufficient lime and promptly till the soil?" Interviewed farmers were asked to respond with either "yes" or "no", with a value of 1 assigned to "yes" responses and a value of 0 assigned to "no" responses.

#### 3.2.2. Core Independent Variables

This paper examines the role of government regulation in the context of the "Remediation and Safe Utilization of Polluted Farmland" project, drawing on the experiences of farmers. To categorize the regulatory approaches as guided, incentive-based, or restrictive, it poses questions such as the following: "How often did you attend training sessions on the safe utilization of technology for heavy metal-polluted farmland this year?" "Do you think the amount of heavy metal and lime released is sufficient?" "Do you think the timing of distributing cadmium low-accumulation seeds and lime aligns with the agricultural season?" "Do you feel that regulatory authorities adequately supervise the implementation of safe utilization technology for heavy metal polluted farmland?".

#### 3.2.3. Mediating Variable

The variable being examined in this study is technological knowledge. Based on previous analysis, technological knowledge is assessed across four dimensions: economic benefits, food security, technological risks, and cost investment. The specific measurement items include the following: "Positively impacting agricultural income", "Improving rice quality standards", "Potential negative effects on rice yield or farmland pollution if not implemented correctly", and "Increasing cost investment". All of the above questions are measured using the Likert five-point scale, with "completely disagree" = 1, "disagree" = 2, "uncertain/neutral" = 3, "agree" = 4, and "completely agree" = 5. To objectively evaluate farmers' technical cognitive abilities, this study draws on relevant research [45] and utilizes the entropy method to assign weights to different technical cognitive indicators. The comprehensive technical cognitive level of farmers is then calculated using a weighted average approach. The weighted values for economic benefit cognition, food safety cognition, technical risk cognition, and cost investment cognition are 0.18, 0.06, 0.31, and 0.45, respectively.

#### 3.2.4. Moderator Variables

The independent variable in this study is self-efficacy, which refers to farmers' confidence level in their ability to implement VIP technology successfully. Self-efficacy is measured across four dimensions: information acquisition, financial investment, labor input, and material acquisition. Example measurement items include the following: "You are capable of easily accessing information regarding heavy metal pollution remediation and technical procedures", "In the absence of government subsidies, your household has the financial ability to cover the costs of implementing remediation technologies", "You possess the necessary time and energy to implement various remediation technologies by technical procedures", and "You can easily procure materials such as low cadmium accumulation rice seeds and lime". Response options are presented using the Likert five-level scale format.

#### 3.2.5. Control Variables

Based on the research conducted by Li Ying-ming [46], Deng Mei-yun [10], and Tong Xing-xing [11], the decision to adopt safe utilization technology for heavy metal-polluted farmland may be influenced by the individual characteristics of household heads, family operations, and farmland. Thus, this study includes age, education level, main participant in farm operation, family agricultural income, number of family members engaged in farming, scale of rice planting, degree of farmland fragmentation, water retention capacity of farmland, and average distance of irrigation water as control variables. More details on each variable can be found in Table 2.

**Table 2.** Description of variables and descriptive statistical analyses.

| Variable Type | Variable Name | Meaning and Valuation | Mean | Standard Deviation |
|---|---|---|---|---|
| Dependent variable | Variety | Do you cultivate cadmium-low-accumulation varieties? No = 0, yes = 1 | 0.76 | 0.43 |
| | Irrigation | Do you maintain a certain flooding depth during rice growth, draining and drying the field 7–10 days before harvest? No = 0, yes = 1 | 0.54 | 0.50 |
| | pH | Do you evenly apply sufficient lime and promptly till the soil? No = 0, yes = 1 | 0.54 | 0.50 |
| Core explanation Variable | Guidance regulation | How often did you attend training sessions on the safe utilization of technology for heavy metal-polluted farmland this year? 0 = 1, 1 = 2, 2 = 3, 3 = 4, 4 or more = 5 | 2.87 | 1.11 |
| | Incentive regulation | Mean value of farmers' evaluation of the quantity and time of distribution of materials | 4.46 | 0.80 |
| | Constraint regulations | Do you feel that regulatory authorities adequately supervise the implementation of safe utilization technology for heavy metal polluted farmland? Very poorly = 1, less well = 2, average = 3, fairly well = 4, very well = 5 | 4.06 | 1.29 |
| Intermediary variable | Technical Cognition | Calculated based on the entropy weight method | 0.54 | 0.22 |
| moderator variable | Self-efficacy | The mean value of farmers' capacity to access information, capital investment, labor inputs, and material acquisition capacity | 3.04 | 1.11 |
| Control variable | Age | <30 = 1, 31~40 = 2, 41~50 = 3, 51~60 = 4, 61 and above = 5 | 3.91 | 1.01 |
| | Educational attainment | Illiterate = 1, Primary school = 2, Middle school = 3, High school = 4, College and above = 5 | 3.02 | 0.99 |
| | Participating in the management entity | Participation in new agricultural enterprises: no = 0, yes = 1 | 0.17 | 0.37 |
| | Family income from agriculture | Actual annual household income from agriculture (USD): below 2765 = 1, 2765 to 5530 = 2, 5530 to 8295 = 3, 8295 to 11,060 = 4, 11,060 and above = 5 | 1.81 | 1.42 |
| | Number of family farmers | Number of laborers in the household engaged in agricultural production | 1.88 | 0.83 |
| | The scale of rice cultivation | Area under rice cultivation (hectare): <0.2 = 1, 0.2~0.34 = 2, 0.34~0.47 = 3, 0.47~0.67 = 4, 0.67 and above = 5 | 2.30 | 1.32 |
| | Degree of cropland fragmentation | Cultivated land area/cultivated plots | 1.03 | 0.79 |
| | Water retention of arable land | Poor = 1, Moderate = 2, Excellent = 3 | 2.09 | 0.59 |
| | Average distance to irrigation water sources | Average distance from irrigation water source to arable land (Km): below 0.05 = 1, 0.05 to 0.1 = 2, 0.1 to 0.5 = 3, 0.5 to 1 = 4, 1 and above = 5 | 2.37 | 1.34 |

### 3.3. Model Settings

#### 3.3.1. Binary Logistic Regression Model

The dependent variable in this study is "farmer's technical adoption behavior", a binary variable. Therefore, this study uses a binary logistic regression model to conduct a direct effect analysis. The model is specified as follows:

$$\text{Logit}\left(Y_{\rangle}\right) = \ln \frac{P_{\rangle}}{1 - P_{\rangle}} = \alpha + \beta \times X_j + \sum_{j=1}^{n} \gamma_j C_j + \mu_{\rangle} \quad (1)$$

In the equation, $Y_{\rangle}$ is farmers' behavior in implementing VIP technology according to the technical regulations; $P_{\rangle}$ represents the probability of farmers implementing the technology according to the technical regulations; $\alpha$, $\beta$, $\gamma_j$ are the parameters to be estimated; $X_j$ is the core explanatory variable, namely environmental regulations; $C_j$ is the control variable; and $\mu_{\rangle}$ is the error term.

#### 3.3.2. Methods for Mediating and Moderating Effects

This paper refers to the moderated mediation analysis model proposed by Preacher and Hayes [47,48] to examine the mediating role of technical cognition and the moderating effect of self-efficacy in implementing VIP technology by farmers under environmental regulations. This model can be tested using the Bootstrap method [49], a powerful non-parametric statistical technique primarily used for estimating and inferring statistics. Its core idea is to simulate the data distribution by repeatedly sampling from the original data to estimate the sampling distribution of statistics [50]. Compared to the stepwise regression method, the Bootstrap testing approach has several advantages [51]. Firstly, the Bootstrap method allows the dependent variable to be two-dimensional, overcoming the limitation of the stepwise method, where the dependent variable can only be continuous. Secondly, the Bootstrap method directly tests the mediation effect without being limited to the premise that the independent variable significantly impacts the dependent variable, effectively avoiding the influence of the "suppression effect". Thirdly, the Bootstrap method integrates mediation and moderation effects into a single analytical framework, preventing the occurrence of omitted variables. The specific conceptual model is as follows:

$$Y_{\rangle} = cX + \mu_1 \quad (2)$$

$$M = aX + \mu_2 \quad (3)$$

$$Y_{\rangle} = c'X + bM + dV + eMV + \mu_3 \quad (4)$$

In the equation, $X$ represents environmental regulations, including guidance regulations, incentive regulations, and constraint regulations; $Y_{\rangle}$ represents the adoption behavior of the $i$-th VIP technology; $M$ represents farmers' technical cognition; $V$ represents farmers' self-efficacy; $a, b, c, c', d$ and $e$ are the coefficients to be estimated; $\mu_1, \mu_2$, $\mu_3$ are random error terms. Equation (2) represents Path I in the diagram, which is the direct impact of environmental regulations on the adoption behavior of VIP technology. Equation (3) represents Path II in the diagram, which is the impact of environmental regulations on the mediating variable of technical cognition. Equation (4) represents Paths III and IV of Figure 1; that is, environmental regulation indirectly influences the adoption behavior of VIP technology through technical cognition regulated by self-efficacy.

## 4. Results and Analysis

### 4.1. Total Impact of Environmental Regulations on Farmers' VIP Technology Adoption Behavior

The independent variables underwent a multi-collinearity diagnosis, excluding consideration of mediating and moderating effects, and no collinearity was detected (VIF < 10). Following this, logistic regression was conducted to evaluate the aggregate impact of environmental regulations on farmers' VIP technology adoption behavior. The chi-square test and predictive accuracy metrics confirmed the regression model's effectiveness, with comprehensive results in Table 3.

**Table 3.** Direct effect test of environmental regulation on farmers' adoption of VIP technology.

| Variant | Variety | | | Irrigation | | | pH | | |
|---|---|---|---|---|---|---|---|---|---|
| | B | Standard Error | Exp (B) | B | Standard Error | Exp (B) | B | Standard Error | Exp (B) |
| Guidance regulation | 0.820 *** | 0.176 | 2.270 | 1.850 *** | 0.254 | 6.361 | 1.680 *** | 0.229 | 5.365 |
| Incentive regulation | 0.448 *** | 0.164 | 1.565 | −0.222 | 0.198 | 0.801 | −0.190 | 0.186 | 0.827 |
| Constraint regulation | 0.462 *** | 0.111 | 1.588 | 0.934 *** | 0.175 | 2.545 | 0.693 *** | 0.150 | 1.999 |
| Age | −0.165 | 0.153 | 0.847 | 0.328 ** | 0.158 | 1.388 | 0.323 ** | 0.150 | 1.382 |
| Educational attainment | −0.094 | 0.158 | 0.910 | 0.377 ** | 0.166 | 1.457 | 0.288 * | 0.157 | 1.334 |
| Participating in the management entity | 0.300 | 0.691 | 1.349 | 2.127 *** | 0.707 | 8.392 | 1.795 *** | 0.648 | 6.017 |
| Family income from agriculture | −0.043 | 0.181 | 0.958 | −0.135 | 0.165 | 0.873 | −0.065 | 0.158 | 0.937 |
| Number of family farmers | 0.242 | 0.185 | 1.274 | 0.765 *** | 0.204 | 2.150 | 0.656 *** | 0.191 | 1.926 |
| The scale of rice cultivation | 0.041 | 0.138 | 1.042 | 0.223 | 0.148 | 1.250 | 0.026 | 0.138 | 1.027 |
| Degree of cropland fragmentation | 0.082 | 0.243 | 1.085 | −0.516 ** | 0.212 | 0.597 | −0.328 * | 0.198 | 0.720 |
| Water retention of arable land | 0.513 ** | 0.254 | 1.670 | 0.934 *** | 0.273 | 2.545 | 0.914 *** | 0.259 | 2.494 |
| Average distance to irrigation water sources | −0.086 | 0.111 | 0.918 | 0.154 | 0.118 | 1.166 | 0.103 | 0.111 | 1.109 |
| Constant | −5.066 | 1.228 | 0.006 | −14.104 | 1.827 | 0.000 | −11.882 | 1.606 | 0.000 |
| −2 log-likelihood | | 339.955 | | | 310.672 | | | 341.396 | |
| Cox Snell R2 | | 0.285 | | | 0.496 | | | 0.460 | |
| Negolko R2 | | 0.428 | | | 0.663 | | | 0.614 | |
| chi-square test | | 149.739 | | | 306.563 | | | 275.212 | |
| Predictive accuracy | | 85.20% | | | 85.00% | | | 82.30% | |

Note: ***, **, and * indicate significance at the levels of 1%, 5%, and 10%, respectively.

Generally speaking, all three types of environmental regulations have successfully passed the significance test, suggesting that they can effectively motivate farmers to embrace VIP technologies, thereby validating Hypothesis 1.

Specifically, the guidance regulation has a significant positive impact on farmers' adoption of all three "V", "I", and "P" technologies at the 1% level. This suggests that increased participation in training promotes the use of VIP technologies among farmers. In other words, guidance regulations represented by technical training significantly enhance farmers' engagement in agricultural safety practices. VIP technology systems are professional and complex [34], making self-exploration and independent implementation challenging for farmers. By attending relevant technical training, farmers can ease the difficulty of acquiring the technology and improve their ability to implement the system [52]. This, in turn, increases the likelihood of technology adoption. Additionally, the more training farmers attend, the deeper their understanding of VIP technology systems, further enhancing the possibility of adopting VIP technologies [53].

There are differences in the impact of incentive regulations on farmers' adoption of "V", "I", and "P" technologies. Only "V" technology passes the 1% significance level test, while "I" and "P" technologies do not, which is consistent with the research conclusions of Wang Xiaomin et al. [24]. This indicates that incentive regulations represented by government subsidies only significantly positively affect the cultivation of low-accumulation varieties. Although farmers can receive free supplies from the government for adopting both "V" and "P" technologies, resulting in cost savings, "V" technology has an advantage in ease of use compared to "P" technology, which requires manual application of quicklime [10]. As for "I" technology, farmers generally believe that it does not align with traditional farming practices and can hinder later machine harvesting. The technology lacks both ease of use and usefulness [11], leading to significant resistance to adoption.

In testing the direct effect of VIP technology, the constraint regulation was significant at the 1% level with a positive coefficient. This indicates that the more timely and effective the supervision of inspectors is, the more likely farmers are to adopt VIP technology. On the one hand, strong constraint supervision can inhibit farmers' opportunistic behavior, preventing them from choosing to "lie flat" or "free-ride" [36]. On the other hand, strict supervision also reflects the severity of heavy metal pollution hazards in farmland and the urgency of governance work, enhancing farmers' awareness of farmland protection and their initiative to adopt VIP technology.

Furthermore, different types of environmental regulations have varying degrees of influence on farmers' adoption of VIP technology. Exp (B), known as the odds ratio (OR) value, can analyze the impact of explanatory variables on the explained variable [21]. By analyzing the OR values of the three types of environmental regulations in Table 3, it can be seen that guidance regulations have a stronger influence on farmers' adoption of VIP technology than incentive and constraint regulations. Due to farmers' generally low educational level, neither government subsidies nor strict supervision can break the knowledge barrier to technology adoption. However, guidance regulations such as technical training can break through the barriers of farmers' technical information blockades [54] and help farmers overcome high-cost and difficult-to-master technical barriers [55], facilitating their technology adoption behavior. The effect of constraint regulations is better than that of incentive regulations, which is consistent with the research conclusions of Tang Lin [19], Wang Taixiang [56], and others. The current incentive policies mainly focus on providing free materials such as seeds and quicklime. However, due to the small cultivation area of scattered farmers, the limited material incentives make a very limited contribution to their farming income. On the other hand, planting high-quality rice, vegetables, and other cash crops can bring higher economic income, which is enough to compensate for the increased cost of giving up free materials.

From the perspective of the impact of control variables: age, education level, participation in business entities, number of family farmers, degree of farmland fragmentation, and farmland water retention all affect farmers' adoption of VIP technology at a significance level of 5–10%. (1) Age positively affects "I" and "P" technologies at a 5% significance level. Since older farmers have long been engaged in agricultural production and have rich experience, they have a certain knowledge reserve of "I" and "P" technologies, making it easier for them to adopt new technologies. (2) Education level affects farmers' adoption of "I" and "P" technologies at significance levels of 5% and 10%, respectively. Farmers with a higher education level have stronger information acquisition abilities and can be the first to understand the severity of heavy metal-contaminated farmland and take measures as soon as possible. Moreover, these farmers have strong learning abilities, enabling them to better master and apply "I" and "P" technologies. (3) Participation in business entities positively affects farmers' adoption of VIP technology at a 1% level. Large farmers and cooperatives can generate agricultural economies of scale in technology implementation and provide a mutually trusting environment, making it easier to accept new technologies. (4) The number of family farmers significantly and positively promotes the adoption of "I" and "P" technologies at a 1% level. The implementation of these two technologies requires a lot of time and manpower. Therefore, families with more farmers have more sufficient labor, and technology implementation is more in place. (5) The degree of farmland fragmentation inhibits farmers' adoption of "I" and "P" technologies at levels of 5% and 10%, respectively. When farmland is too scattered, it requires a large investment of time and manpower, resulting in low agricultural production efficiency and uneconomical land scale, thus hindering farmers from adopting new technologies. (6) Farmland water retention significantly and positively affects farmers' adoption of VIP technology at a 5% level. Farmers can more effectively utilize water resources, reduce irrigation costs, and improve crop yield and quality when farmland has good water retention. The economic benefits of this new technology are more significant, increasing farmers' enthusiasm for adopting new technologies.

In order to verify the robustness of the empirical results, this paper uses Bootstrap resampling 1000 times for regression analysis. The regression results are consistent with regular logistic regression results (as shown in Table 4), indicating that the regression results are robust.

**Table 4.** Direct effect test of environmental regulation on farmers' adoption of VIP technology under the Bootstrap approach.

| Variant | Variety | | Irrigation | | pH | |
|---|---|---|---|---|---|---|
| | B | Standard Error | B | Standard Error | B | Standard Error |
| Guidance regulation | 0.820 *** | 0.178 | 1.850 *** | 0.383 | 1.680 *** | 0.300 |
| Incentive regulation | 0.448 ** | 0.183 | −0.222 | 0.182 | −0.190 | 0.186 |
| Constraint regulation | 0.462 *** | 0.129 | 0.934 *** | 0.203 | 0.693 *** | 0.180 |
| Age | −0.165 | 0.172 | 0.328 ** | 0.178 | 0.323 ** | 0.161 |
| Educational attainment | −0.094 | 0.156 | 0.377 ** | 0.177 | 0.288 * | 0.164 |
| Participating in the management entity | 0.300 | 1.437 | 2.127 *** | 0.871 | 1.795 *** | 0.780 |
| Family income from agriculture | −0.043 | 0.241 | −0.135 | 0.191 | −0.065 | 0.180 |
| Number of family farmers | 0.242 | 0.207 | 0.765 *** | 0.253 | 0.656 *** | 0.215 |
| The scale of rice cultivation | 0.041 | 0.165 | 0.223 | 0.167 | 0.026 | 0.158 |
| Degree of cropland fragmentation | 0.082 | 0.204 | −0.516 *** | 0.210 | −0.328 ** | 0.193 |
| Water retention of arable land | 0.513 ** | 0.270 | 0.934 *** | 0.321 | 0.914 *** | 0.308 |
| Average distance to irrigation water sources | −0.086 | 0.120 | 0.154 | 0.140 | 0.103 | 0.125 |
| Constant | −5.066 | 1.305 | −14.104 | 2.221 | −11.882 | 1.732 |

Note: ***, **, and * indicate significance at the levels of 1%, 5%, and 10%, respectively.

### *4.2. Test of the Conditional Mediating Role of Technical Cognition*

This paper uses SPSS macro (Process program) to examine the mediating role of technical cognition and the moderating effect of self-efficacy in environmental regulation affecting farmers' adoption of VIP technology. Both the conditional mediating and moderating effects are tested using the Bootstrap method (with 5000 repetitions of resampling) to obtain robust standard errors for parameter estimates and 95% bias-corrected confidence intervals. The test result of the mediating effect can be judged based on whether the confidence interval in the conditional mediating effect does not include zero. The test result of the moderating effect can be determined based on differences in the mediating effect coefficients under different groups and the moderated mediation effect index. The Bootstrap method categorizes the moderating variables into high, average, and low levels by adding or subtracting one standard deviation from the mean. The specific test results are shown in Table 5.

The results of conditional indirect effects in Table 5 show that the confidence intervals for the mediating effect of technical cognition do not include zero in the relationship between guidance regulation, incentive regulation, and constraint regulation on farmers' VIP technology adoption behavior. This suggests that technical cognition positively mediates in the environmental regulation process affecting farmers' adoption of VIP technology, thus validating Hypothesis H2. This is consistent with the expected hypothesis of the S-O-R theory [31]. The results indicate that different environmental regulations, such as technical training, government subsidies, and supervisory punishments, shape farmers' positive technical cognition of VIP technology from different perspectives, influencing their behavioral preferences. For example, increasing the frequency of training and focusing on training quality can deepen farmers' understanding of the usefulness of technology and facilitate their mastery of technical essentials, reducing uncertainty in the technology implementation process [52]. Both the conditional mediating and moderating effects are tested using the Bootstrap method (with 5000 repetitions of resampling) to obtain robust standard errors for parameter estimates and 95% bias-corrected confidence intervals. Strengthening supervision and punishment can increase the cost of farmers' violations or negative farmland management, thus prompting them to adopt farmland ecological protection technologies [57].

**Table 5.** Conditional mediation and moderating effect test results.

| VIP Technology | Conditional Indirect Effect | | | | | | Moderated Mediation Effect | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Environmental Regulation | Self-Efficacy | Coefficient | Boot Standard Error | 95% Confidence Interval | | Index | Boot Standard Error | 95% Confidence Interval | |
| | | | | | Lower Limit | Upper Limit | | | Lower Limit | Upper Limit |
| Variety | Guidance regulation | Low level | 0.615 | 0.174 | 0.353 | 1.036 | 0.183 | 0.135 | −0.063 | 0.478 |
| | | average | 0.819 | 0.191 | 0.555 | 1.307 | | | | |
| | | High level | 1.023 | 0.296 | 0.593 | 1.741 | | | | |
| | Incentive regulation | Low level | 0.327 | 0.105 | 0.171 | 0.585 | 0.093 | 0.069 | −0.024 | 0.250 |
| | | average | 0.431 | 0.118 | 0.256 | 0.723 | | | | |
| | | High level | 0.534 | 0.169 | 0.292 | 0.956 | | | | |
| | Constraint regulation | Low level | 0.339 | 0.106 | 0.184 | 0.597 | 0.103 | 0.076 | −0.027 | 0.272 |
| | | average | 0.453 | 0.107 | 0.310 | 0.724 | | | | |
| | | High level | 0.567 | 0.161 | 0.349 | 0.976 | | | | |
| Irrigation | Guidance regulation | Low level | 0.156 | 0.421 | −0.637 | 1.009 | 0.873 | 0.471 | 0.301 | 2.047 |
| | | average | 1.126 | 0.361 | 0.755 | 2.107 | | | | |
| | | High level | 2.096 | 0.794 | 1.276 | 4.232 | | | | |
| | Incentive regulation | Low level | 0.150 | 0.223 | −0.256 | 0.618 | 0.430 | 0.246 | 0.122 | 1.056 |
| | | average | 0.629 | 0.202 | 0.386 | 1.177 | | | | |
| | | High level | 1.107 | 0.426 | 0.614 | 2.261 | | | | |
| | Constraint regulation | Low level | 0.113 | 0.241 | −0.337 | 0.624 | 0.511 | 0.264 | 0.173 | 1.177 |
| | | average | 0.681 | 0.206 | 0.465 | 1.230 | | | | |
| | | High level | 1.249 | 0.447 | 0.746 | 2.427 | | | | |
| pH | Guidance regulation | Low level | 0.285 | 0.330 | −0.352 | 0.946 | 0.662 | 0.343 | 0.167 | 1.510 |
| | | average | 1.021 | 0.260 | 0.687 | 1.715 | | | | |
| | | High level | 1.757 | 0.564 | 1.036 | 3.248 | | | | |
| | Incentive regulation | Low level | 0.193 | 0.169 | −0.087 | 0.558 | 0.324 | 0.183 | 0.070 | 0.775 |
| | | average | 0.553 | 0.165 | 0.343 | 0.990 | | | | |
| | | High level | 0.913 | 0.329 | 0.490 | 1.775 | | | | |
| | Constraint regulation | Low level | 0.163 | 0.179 | −0.164 | 0.549 | 0.378 | 0.184 | 0.103 | 0.841 |
| | | average | 0.583 | 0.146 | 0.401 | 0.970 | | | | |
| | | High level | 1.003 | 0.307 | 0.596 | 1.831 | | | | |

Note: A bias-corrected non-parametric percentile Bootstrap method with 5000 repetitions is used here.

### *4.3. Test of the Moderating Effect of Self-Efficacy*

The results of the moderated mediation effects in Table 5 indicate that the regulatory role of guidance regulations, incentive regulations, and constraint regulations on the indirect effects of farmers' adoption of "V" technology through technological cognition is judged by the 95% confidence intervals of the INDEX, which are [−0.0663, 0.478], [−0.024, 0.250], and [−0.027, 0.272], respectively. Since all confidence intervals include 0, these three moderated mediation effects are insignificant. As shown in Figure 2, when self-efficacy levels are low, the confidence intervals of the mediation effects of guidance regulations, incentive regulations, and constraint regulations on farmers' adoption of "I" and "P" technology through technological cognition all include 0, indicating that the mediation effects are not significant. However, when self-efficacy levels are high, the confidence intervals of these mediation effects do not include 0, indicating that the mediation effects are significant. Furthermore, combining the moderated mediation effects in Table 5, we find that the confidence intervals of the INDEX for all six moderated mediation effects do not include 0, indicating that these effects are significant. These results suggest that as self-efficacy levels increase, the mediation effects of guiding, incentive, and constraint regulations on farmers' adoption of "I" and "P" technology through technological cognition gradually strengthen, partially validating Hypothesis H3.

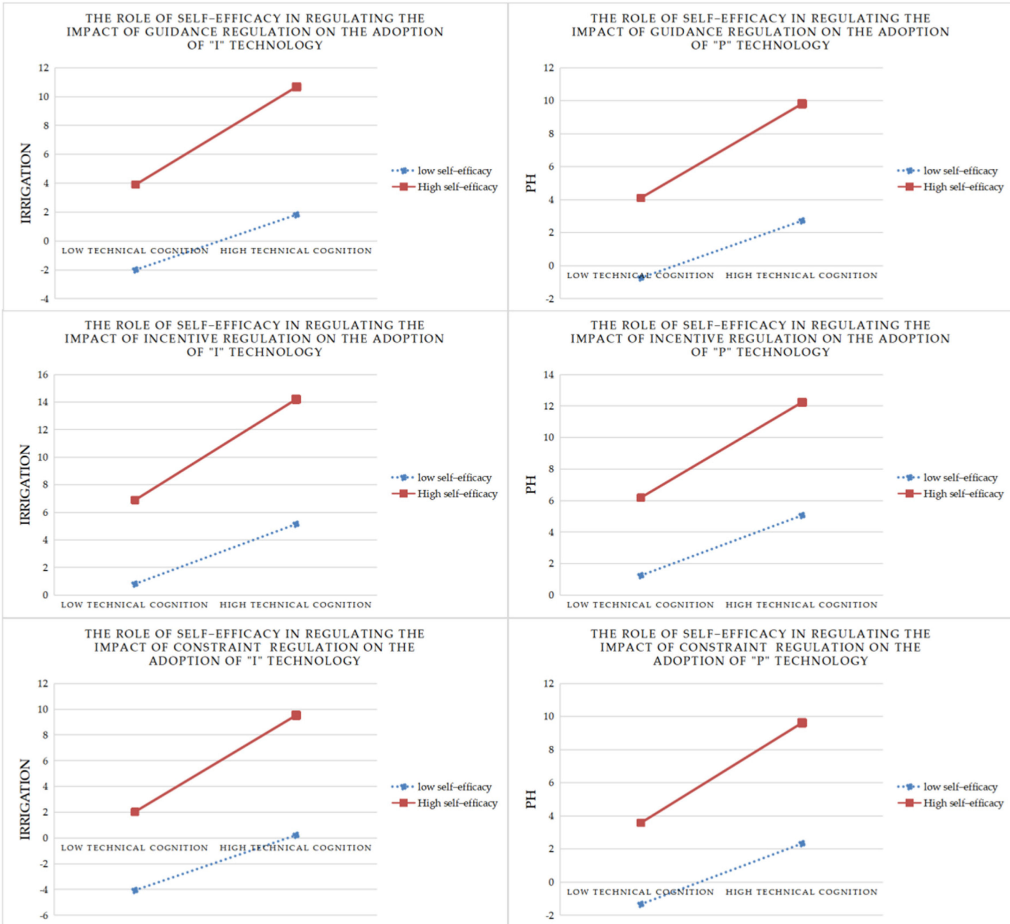


**Figure 2.** Diagram of moderated mediation effects.

This outcome is partly linked to farmers' perceptions of different technologies. Respondents generally believe that among the three technologies of "V", "I" and "P", "V" technology offers better usability and usefulness [10]. Therefore, farmers are more willing to adopt "V" technology in response to environmental regulations, resulting in the highest implementation rate of over 70% [10]. This partly explains why the mediating effect of self-efficacy on the cognition of "V" technology is not significant. However, the mediating role of technological cognition in environmental regulations influencing farmers' adoption of "I" and "P" technologies is closely related to their level of self-efficacy. Specifically, the mediating effect of technological cognition is insignificant in the low self-efficacy group but significant in both the average and high self-efficacy groups. When facing complex technologies, even if farmers are at the same cognitive level, those with low self-efficacy tend to activate their defense mechanisms when dealing with implementation challenges and difficulties [30,43]. Therefore, regardless of the type of environmental regulations employed, changing their fixed mindset, and encouraging them to take action is difficult. Hence, enhancing farmers' self-efficacy is crucial for improving the mediating effect of technological cognition and achieving environmental regulation goals.

## 5. Conclusions and Recommendations

### *5.1. Conclusions*

This paper integrates environmental regulations, technological understanding, self-efficacy, and adoption behavior within the S-O-R theoretical framework. The study examines the direct influence of environmental regulations on farmers' adoption behavior of VIP technologies, along with the mediating effect of technological understanding and the moderating effect of self-efficacy. The conclusions are as follows:

Firstly, different environmental regulations directly influence farmers' adoption of technology. The impact of these regulations can be categorized in the following order: guidance regulation, constraint regulation, and incentive regulation. Specifically, guidance regulation and constraint regulation have a positive influence on farmers' adoption of the "V", "I", and "P" technologies. In contrast, incentive regulation only significantly affects farmers' adoption of the "V" technology.

Additionally, cognitive technology serves as a mediator in the impact of environmental regulations on farmers' adoption of "V", "I", and "P" technologies. This result validates the notion that external environmental factors influence internal perceptions in the S-O-R theory, thereby shaping farmers' behavior toward technology adoption.

Thirdly, self-efficacy has a beneficial moderating impact on how environmental regulations influence farmers' decisions to adopt "I" and "P" technologies through cognitive technology. However, this moderating effect is insignificant in how environmental regulations influence farmers' decisions to adopt "V" technology through cognitive technology.

### 5.2. Recommendations

To enhance the effectiveness of environmental regulations, we must strengthen top-level design, clarify objectives, and leverage the combined effects of various regulatory types. Given farmers' low literacy levels and technology complexity, we will strengthen guidance regulations by increasing technical training efforts, combining group training with expert guidance to help farmers understand and master VIP technology. To further address the issues of small planting areas and low agricultural income among individual farmers, we can optimize incentive regulations by introducing technical subsidies in the form of "materials + funding" and a market-oriented mechanism for grain storage and purchase that rewards high-quality grain with higher prices. Additionally, to tackle heavy metal pollution in farmland, we will improve accountability systems for farmland management in grassroots government departments, effectively enhancing the effectiveness of constraint regulations to restrict further the behaviors of agricultural production and management entities, such as farmers.

To enhance farmers' technological cognition, we suggest optimizing technical measures and strengthening promotion and outreach. By developing more popular grain varieties, we can ensure food production safety and significant farmer income. Regarding the "I" and "P" technologies rejected by farmers, we will utilize new media for vivid interpretations and deepen farmers' understanding through lectures, training, and expert platforms, thereby increasing their enthusiasm for adoption.

To alleviate farmers' self-efficacy pressure, we propose cultivating new agricultural business entities, such as farmer cooperatives and family farms, to promote moderate-scale operations and enhance the effectiveness of policy incentives. Simultaneously, we should establish socialized service organizations to build information exchange platforms between technical experts and farmers, provide technical services, break down information barriers, strengthen farmers' self-efficacy, and facilitate their technology adoption.

### 5.3. Limitations

The cost of restoring heavy metal-polluted farmland is immense, and only limited efforts have been made in Japan and Taiwan, China. This paper shares China's successful experience in large-scale remediation and offers valuable suggestions to enhance governance efficiency from three perspectives: environmental regulations, farmers' technical knowledge, and self-efficacy. These suggestions serve as a reference for other regions globally.

However, this study has some limitations. Firstly, it assumes "rational farmers" whose decisions follow cost–benefit principles. Nevertheless, there are inevitably farmers who are not fully rational. Future research could consider the behavior of non-fully rational farmers to bridge the gap between theoretical models and reality. Secondly, regarding factors influencing farmers' technology adoption, more social and environmental variables like social capital and social norms should be included. This is another limitation of this study. Lastly, a static approach was employed, but a dynamic method would be more reliable in assessing the progress of farmers' technology adoption and the effectiveness of policies. Future studies should consider these limitations.

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**Institutional Review Board Statement:** The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the College of Commerce, Hunan Agricultural University. The study was conducted under its supervision. All participants provided their informed consent to participate prior to the start of the survey. They were informed about the aim of the study and that they could terminate their participation at any time without negative consequences. Ethical review and approval were waived for this study by the institutional review board and did not involve animal experiments or human clinical trials. All respondents participated voluntarily and gave their written informed consent following the Declaration of Helsinki, as well as their commitment to keep their personal information confidential to ensure anonymity.

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

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