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Does Farmers' Cognition Enhance Their Enthusiasm for Adopting Sustainable Digital Agricultural Extension Services? Evidence from Rural China

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Abstract: The service model of digital agricultural technology extension, as a novel and sustainable approach, plays a pivotal role in facilitating the digital transformation of farmers' agricultural practices. Leveraging survey data from 1475 farmers in China, the study employed a multivariate ordered logit model to investigate the relationship between farmers' cognition and enthusiasm to adopt digital agricultural extension services. The findings revealed that subjective and objective cognitions positively influence farmers' enthusiasm for adopting digital agricultural extension services. Furthermore, policy incentives, as a significant regulatory factor, effectively influence farmers' cognition levels and enthusiasm to adopt digital agricultural extension services. Additionally, female respondents, farmers with higher educational levels, and membership in agricultural cooperatives all facilitate the adoption of these services. This study not only enriches the theoretical framework for agricultural technology promotion, aiding in the understanding of farmers' decision-making processes when adopting digital agricultural extension services, but also provides a deeper insight into the role of digital agricultural technologies in promoting sustainable agricultural development, offering scientific evidence for relevant policy formulation and implementation.

Keywords: farmers' cognition; digital agricultural extension services; adopt enthusiasm; sustainable development; policy incentives; rural areas of China

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1. Introduction

With its rapid development, internet technology has penetrated vast rural areas, leveraging its unique advantages of transcending time and space, reaching a broad audience, and being cost-effective [1]. This integration has significantly altered farmers' economic behavioral patterns, infusing new vitality, presenting viable pathways for rural entrepreneurial economic transformation, and advancing farmers' entrepreneurship. Meanwhile, the emergence of mass media and the digital landscape has spurred traditional media such as radio and television to explore digital promotion methods [2,3]. However, conventional extension service models, involving visits to villages and relying on newspapers and magazines, suffer from timeliness and relevance issues. Experts' direct visits to production sites are time-consuming and laborious, with content limitations and weak interaction. Guided by digital technology, the internet's rapid rise has genuinely digitized agricultural extension services, enhancing farmers' access to agriculture-related technology and information. This has revolutionized the traditional agricultural extension service model, promising new prospects [4,5]. Nevertheless, online promotion methods based on digital networks have long been a weakness in the farm industry, often sporadic and resulting in low utilization and dissemination rates of digital agricultural extension services [6,7].

In summary, digital agricultural extension services empower farmers with real-time weather, pest, and market information, enhancing risk prediction and management. However, only farmers with strong information and cognitive skills can use these services effectively; otherwise, their enthusiasm may suffer [8].

In theory, cognition is a subjective perception of risk, influenced by personal experience and knowledge. Cognition significantly impacts farmers' enthusiasm for adopting digital agricultural extension services [9]. Objective cognition relies on factual data such as scientific research and statistics, providing a theoretical basis for farmers' behavior and decision-making in using digital agricultural extension services [10]. Subjective cognition, based on farmers' beliefs and values, also plays a crucial role in processing external information [11,12]. Farmers' adoption of digital agricultural extension services is influenced by external factors such as cost, benefits, and objective and subjective cognition of information channels, as well as internal factors such as internal knowledge and experience. Therefore, farmers' use of digital agricultural extension services is significantly influenced by their objective cognition of external costs, benefits, and information channels, as well as their subjective cognition of internal knowledge, emotions, and personal beliefs.

However, there is still limited empirical evidence on the impact of farmers' cognition on the adoption of digital agricultural extension services. Most studies on farmers' cognition focus on the effect of single-dimensional cognition, such as risk perception, income perception, ecological perception, and technology perception, on agricultural technology adoption [11–18]. For digital agricultural extension services, most studies focus on qualitative research on the current status, problems, and advantages [1,6,7]. Although a few scholars have paid attention to quantitative studies on agricultural production efficiency [19,20], farmers' consumption behavior [5], and household income [21], no studies have yet focused on the impact of farmers' cognition on digital agricultural extension services. Few studies have analyzed the mechanisms of farmers' subjective and objective cognition of digital agricultural extension services from the perspective of government support.

Compared with the existing literature, the innovations of this paper are as follows: (1) From the perspective of research, although existing studies have paid attention to the influence of farmers' cognition or policy incentives on farmers' adoption behavior of digital agricultural extension services, there is a lack of integrating the three into the same analytical framework, and especially a lack of research on the regulatory mechanism of policy incentives on the relationship between farmers' cognition and enthusiasm for adopting digital agricultural extension services. (2) In terms of research content, farmers' cognition is composed of various subjective and objective factors, including personal beliefs, emotional attitudes, knowledge and experience, cost cognition, economic benefits, and information channel cognition. Most of the literature on the research of farmers' adoption of digital agricultural extension services analyzes the current situation from a qualitative perspective or conducts empirical research from a single dimension of digital agricultural extension services (such as service methods like mobile phones and computers, or a certain technical service information in service content), which is just staying at the level of experience summarization. (3) In terms of research methods, most studies use multiple linear regression models and binary logit models, which cannot effectively address the issue of farmers' enthusiasm for adopting digital agricultural extension services. (4) From the perspective of research regions, there are few quantitative studies on the adoption of digital agricultural extension services by fruit and vegetable growers in Shandong, Shanxi, and Shaanxi, the major fruit and vegetable planting provinces in China, based on large-scale field survey data.

Therefore, this study utilized 1475 data samples of fruit and vegetable growers from Shandong, Shaanxi, and Shanxi provinces in eastern, central, and western China, and employed a multivariate ordered logit model to explore the impact of farmers' cognition on service enthusiasm and analyze the moderating effect of policy incentives. The aim was to improve farmers' subjective and objective cognition, providing theoretical support and

decision-making references for the government to promote new agricultural technology promotion service models and promote sustainable agricultural sustainable development.

2. Theoretical Analysis Framework

Various researchers and experts have proposed numerous theories and models to study people's enthusiasm through cognitive psychology perspectives, such as the planned behavior theory, technology acceptance theory, and reciprocal determinism. These theories are highly applicable to agricultural and rural sustainable development [22].

Objective cognitive factors, such as self-assessment and external control, impact farmers' enthusiasm in adopting digital agricultural extension services: (1) Farmers' understanding of the costs associated with digital agricultural extension services, including time, money, and effort, can affect their enthusiasm. The perception that these services may burden or trouble them could deter adoption [18]. (2) Farmers' comprehension of the economic benefits of using digital agricultural extension services, leading to enhanced agricultural production efficiency, cost reduction, increased income, better market opportunities, and heightened enthusiasm for adoption [23]. (3) Farmers' clear understanding of the channels for obtaining digital agricultural extension services can positively influence their enthusiasm for adoption. Access to relevant information through digital platforms, agricultural extension agencies, social media, and other channels can help them better understand the services and encourage active adoption [24].

Subjective cognitive factors, such as knowledge, experience, personal convictions, and emotional attitudes, also affect farmers' enthusiasm for adopting digital agricultural extension services. Specifically: (1) Familiarity with agricultural knowledge, skills, and prior experience with digital agricultural extension services can boost farmers' confidence and understanding of these services, enhancing their enthusiasm for adoption [25]. (2) Farmers' trust in digital agricultural extension services amplifies their belief in technology providing reliable solutions. Personal solid convictions lead to a positive attitude and increased enthusiasm for using these services [26]. (3) A positive emotional attitude towards digital agricultural extension services, perceiving them as simple, convenient, and easy to understand and operate, encourages farmers to try and adopt these services [27].

Bandura's "reciprocal determinism" emphasizes the interplay between individuals and their environment in determining human behavior. They posit that individuals and the environment are interconnected and mutually influence each other. The environment impacts individuals, and in turn, individuals can affect the environment through their behaviors and reactions [12]. Farmers' cognition forms the foundation for understanding the use of digital agricultural extension services. However, given that personality variables and situational factors are dynamic, policy incentive scenarios can help farmers fully realize the potential and advantages of using digital agricultural extension services. This support boosts their confidence and ability to use the services, ultimately enhancing their enthusiasm for adoption [28]. Therefore, within the context of policy incentives, utilizing the planned behavior theory and personal interaction theory to investigate farmers' cognition regarding enthusiasm for adopting digital agricultural extension services holds significant policy practicality.

Based on the above analysis, this paper shows the research framework in Figure 1 and puts forward the following three hypotheses:

H1: *Subjective cognition positively influences farmers' enthusiasm for adopting digital agricultural extension services.*

H2: *Objective cognition positively influences farmers' enthusiasm for adopting digital agricultural extension services.*

H3: *Policy incentives moderates farmers' cognition and enthusiasm for adopting digital agricultural extension services.*

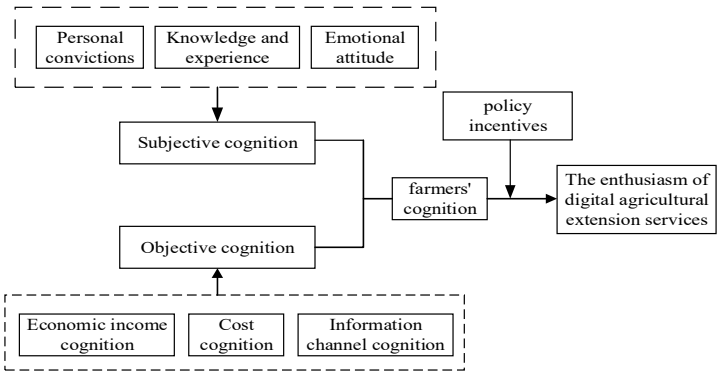

Figure 1. The theoretical model of farmers' cognition–adoption enthusiasm relationship in the context of policy incentives.

3. Data Source, Model Construction, and Variable Selection

3.1. Data Sources

In October 2019 and November 2020, the research team surveyed the awareness and adoption of digital agricultural extension services among fruit and vegetable farmers in Shandong, Shaanxi, and Shanxi provinces. The reasons for selecting these survey locations are as follows: Shandong, located in the eastern region of China, is a province renowned for its vegetable cultivation, boasting a long agricultural history and abundant agricultural resources; Shaanxi, situated in the western region of China, has fostered numerous high-quality fruit and melon varieties due to its unique geographical environment and climatic conditions; and Shanxi, situated in the central region of China, has a profound tradition and advantage in fruit tree cultivation. Therefore, selecting these provinces as research samples can more comprehensively reflect the characteristics and differences in agricultural development in the eastern, central, and western regions of China.

Indeed, with the continuous development of digital technology in recent years, more and more farmers have begun to accept and adopt digital agricultural extension services. In these three provinces, farmers in many regions have started to utilize digital technology for agricultural production and management, achieving specific results [18]. By comparing and analyzing data from these different provinces, we can further explore the promotion strategies of digital agricultural extension services under various conditions, thereby enhancing the universality and guiding the significance of the research results, as well as providing beneficial references for other regions. Therefore, studying the application of digital agricultural extension services in these three provinces also possesses a certain degree of advancement and universality.

The research methodology used in this article employed stratified random sampling to collect a total of 1481 questionnaires from four counties across three provinces. The reasons for adopting stratified random sampling are that it can make full use of known information about the population, and divide the population into multiple strata or types based on specific criteria. In each stratum, the number of samples is determined based on the ratio of the number of units in the stratum to the total number of units in the population, and samples are randomly selected. This ensures that the sample units in each stratum are highly representative of that stratum, thus enhancing the representativeness of the entire sample to the population. Moreover, stratified random sampling results in a more even and reasonable distribution of sample units in the population, reducing the possibility of extreme values and making the sample closer to the actual situation of the population. Additionally, it can reduce survey costs. By dividing the population into multiple strata and conducting random sampling in each stratum, the sample size can be effectively controlled, thus saving significant human and material resources [29,30]. During the sampling process, the research team first selected cities and counties based on their economic and informatization levels and subsequently chose townships and villages randomly. To guarantee the accuracy of the data, the research team revised the

questionnaire based on the results of a pre-survey and trained the researchers. With the consent of the respondents, the research team conducted face-to-face household interviews and recorded the interview process. The questionnaire encompassed farmers' personal and household characteristics, production details, usage of agricultural technology extension services, and information acquisition channels. After carefully reviewing and eliminating invalid or inconsistent data, a total of 1475 valid questionnaires were obtained, representing a high valid response rate of 99.59%. Among the valid samples, there were 800 respondents from Shandong, 310 from Shaanxi, and 365 from Shanxi.

3.2. Model Setting

Assume that the subjective probability (P) of farmers using digital agricultural extension services is influenced by many factors, and the expression is:

$$P = P(y = 1) = F(X\,\beta) \tag{1}$$

In the formula, y ranges from 1 to 5, which indicates the degree of farmers' activity in investing time and energy in the use of digital agricultural extension services, ranging from very inactive to very active; X is a vector of variables that may influence farmers' enthusiasm for adopting digital agricultural extension services.

In this article, the multivariate ordered logit model was employed to analyze the relationship between farmers' activity levels (y ranging from 1 to 5) in adopting digital agricultural extension services and the variables (X) that may have influenced their adoption. This choice was primarily made because, firstly, the multivariate ordered logit model was adept at handling ordinal categorical data. In this study, farmers' activity levels were classified into ordered categories ranging from very inactive to very active, which were not suitable for analysis using simple linear or logistic regression models. By considering the ordinal relationship between different categories, the multivariate ordered logit model could more accurately depict the relationship between variables [31]. Secondly, the model allowed for the inclusion of multiple independent variables and analyzed their impact on the ordinal dependent variable. When studying the impact of cognitive factors on farmers' enthusiasm for adopting digital agricultural technology extension services, other factors, such as farmers' age, education level, economic status, and family structure, may have also played a role. The multivariate ordered logit model could comprehensively consider these factors, thus revealing the factors influencing farmers' activity levels in a more comprehensive manner [32]. Finally, the model provided parameter estimates and interpretations, enabling researchers to understand the direction and extent of the impact of each independent variable on the dependent variable, which is crucial for developing targeted promotion strategies. The formula is as follows:

$$\mathrm{In}\left(\frac{P}{1-P}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \beta_n x_n + \varepsilon \tag{2}$$

In the formula, x includes core explanatory variables (such as farmers' subjective cognition (knowledge and experience, personal convictions, and emotional attitudes), objective cognition (cost cognition, economic income cognition, and information channel cognition), and control variables (such as the age and gender of the respondents). $\frac{P}{1-P}$ is called the probability ratio or relative risk, β_0 is an intercept term, and ε is a random error term.

3.3. Variable Selection

(1) The interpreted variable. Based on the research by Gao et al. [18] the questionnaire set up the question "How enthusiastic are you about the use of digital agricultural extension services" in order to obtain the adoption enthusiasm of sample farmers. Farmers' enthusiasm for adoption was assigned as "very inactive = 1, not very active = 2, average = 3, relatively active = 4, very active = 5".

(2) Core explanatory variables. This survey draws lessons from Wang et al. [7], aiming understand farmers' cognition from both subjective and objective cognition. In order to evaluate farmers' cognitive status, the questionnaire includes the following questions about subjective and objective cognition:
"Do you have knowledge and experience in using digital technology to obtain agricultural information? "
"Do you have confidence in using digital technology to obtain agricultural information?"
"Are you actively interested in using digital technology to obtain agricultural information?"
"Do you think using digital technology to obtain agricultural information will reduce costs?"
"Do you think using digital technology to obtain agricultural information will increase economic income? "
"Do you have a clear understanding of the information channels for obtaining digital agricultural extension services?"

(3) Control variables. Drawing inspiration from relevant studies such as Mao et al. [5] and Gabriel et al. [9], this paper considers factors such as the respondent's gender, age, education level, health status, farmland area, labor ratio, organizational participation, and other factors that influence farmers' enthusiasm for using digital agricultural extension services as control variables. Among them, for the health status variable, this paper refers to the setting of self-rated health status variables in Yang and He's [33] study on Chinese residents. During the survey, we inquired about the respondent's health status by asking, "How do you rate your health? (perennial illness = 1, average = 2, very good = 3)", to characterize the health status of the respondents.

(4) Adjusting variables. While some markets may not reflect it, there are significant factors affecting farmers' well-being in digital agricultural extension services. These factors include government incentives for digital agricultural extension services and the related infrastructure. In order to measure the degree of policy incentives, this paper draws lessons from the research by Bi and Xia [34] and Yang et al. [35], and puts forward some specific questions to farmers, including the following:
"Do you believe that the government provides financial support through digital investment subsidies, loans, and tax reductions?"
"Do you think the government offers technical support through digital network training and guidance?"
"Do you have confidence in the government providing legal support, including legal consulting services, legal supervision, judicial oversight, and other measures?"

These three dimensions are utilized to assess policy incentives variables. Research by Gao et al. [1] has demonstrated that when traditional agricultural extension services fail to provide timely and effective agricultural information, farmers tend to resort to the internet for agricultural extension services. Moreover, the government's technical support, financial subsidies, and legal regulations in social services related to agricultural extension all significantly encourage farmers to adopt these services. Table 1 provides a comprehensive breakdown of the variables and their specific designations.

Table 1. Descriptive statistics of variables.

Variable	Assignment Standard	Min	Max	Mean	Std. Dev.
Explained variable					
Adopt enthusiasm	Very inactive = 1, not very active = 2, average = 3, relatively active = 4, very active = 5.	1	5	3.367	1.074
Core explanatory variable					
Subjective cognition					
Knowledge and experience	Do you have knowledge and experience in using digital technology to obtain agricultural information? Yes = 1, no = 0.	0	1	0.456	0.498
Personal convictions	Do you have confidence in using digital technology to obtain agricultural information? Yes = 1, no = 0.	0	1	0.283	0.450
Emotional attitude	Are you actively interested in using digital technology to obtain agricultural information? Yes = 1, no = 0.	0	1	0.618	0.486
Objective cognition					
Cost cognition	Do you think using digital technology to obtain agricultural information will reduce costs? Yes = 1, no = 0.	0	1	0.688	0.463

Table 1. *Cont.*

Variable	Assignment Standard	Min	Max	Mean	Std. Dev.
Economic income cognition	Do you think using digital technology to obtain agricultural information will increase economic income? Yes = 1, no = 0.	0	1	0.784	0.411
Information channel cognition	Do you have a clear understanding of the information channels for obtaining digital agricultural extension services? Yes = 1, No = 0.	0	1	0.556	0.497
Control variable					
gender	Male = 0, female = 1	0	1	0.682	0.466
age	Age (years)	20	84	51.323	8.808
Degree of education	Time of education (year)	0	16	7.514	3.183
Health degree	Perennial illness = 1, average = 2, very good = 3.	1	3	2.742	0.487
agricultural acreage	Family cultivated land area (Hectare)	0.5	120	9.314	10.384
Labor force proportion	Proportion of household labor force (%)	0	1	0.686	0.228
Degree of organization	Whether to join the cooperative: Yes = 1, No = 0.	0	1	0.329	0.470
Virtual variables in Shanxi province	The province where farmers are located is Shanxi Province = 1, others = 0.	0	1	0.247	0.432
Virtual variables in Shaanxi province	The province where farmers are located is Shaanxi Province = 1, others = 0.	0	1	0.210	0.408
Regulated variable					
Financial service support	In place = 1, not in place = 0	0	1	0.873	0.334
Technical service support	In place = 1, not in place = 0	0	1	0.570	0.495
Legal service support	In place = 1, not in place = 0	0	1	0.516	0.500

3.4. Variable Description Statistics

According to the data presented in Table 1, the majority of respondents are male, constituting 68% of the total, while female respondents account for 32%. Regarding age distribution, the age of respondents ranges from 20 to 84 years, with an average age of 51 years. On average, respondents have received 7.5 years of education, indicating a generally good level of education. Most have completed at least junior high school and possess proficiency in using modern communication methods such as mobile phones and computers. This educational foundation facilitates their access to agricultural information via online platforms. Assessing the health status of respondents, it falls within the average to good range. Additionally, approximately 69% of households have family members contributing to labor, implying a more substantial production capacity for families engaged in agriculture. This enables them to effectively handle agricultural production tasks and make informed decisions regarding the use of digital agricultural extension services. Analyzing family organization, the data reveal that only 33% of farmers are part of cooperatives, suggesting a relatively low level of organizational involvement within the farming community.

3.5. Model Inspection Method

Correlation analysis: To improve the accuracy and significance of the results, this paper tested the correlation between the independent variables (Table 2) to initially grasp the covariation trends between variables and measure the close relationship between two variables [36,37]. The test results indicate that the correlation between each variable is less than 0.8.

Table 2. Correlation between main variables.

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) Adopt enthusiasm	1.000									
(2) Knowledge and experience	0.163	1.000								
(3) Personal convictions	0.067	0.064	1.000							
(4) Emotional attitude	0.025	0.079	0.265	1.000						
(5) Cost cognition	0.063	0.375	0.029	0.009	1.000					
(6) Economic income cognition	0.004	0.401	0.044	0.096	0.171	1.000				
(7) Information channel cognition	0.146	0.105	0.193	0.122	0.032	0.190	1.000			
(8) Financial service support	0.102	0.235	0.013	0.026	0.138	0.111	0.067	1.000		
(9) Technical service support	0.004	0.016	0.157	0.334	0.066	0.019	0.150	0.042	1.000	
(10) Legal service support	0.012	0.108	0.223	−0.581	0.030	0.046	0.175	0.045	0.337	1.000

Multicollinearity test: recognizing the potential internal correlation between subjective and objective variables in farmers' cognition, this paper used SPSS19.0 software to diagnose and address the issue of multicollinearity among variables [38]. The cost cognition in objective cognition was set as the dependent variable, while other variables served as independent variables. Subsequently, regression analysis was conducted using the enter

method, and this process was repeated for the remaining variables (Table 3). The results reveal that the tolerance among variables ranges from 0.1 to 1, and the variance inflation factor is less than 10, indicating no presence of collinearity (VIF < 10). Therefore, this paper believes that there is no severe multi-collinearity among the variables, and the multicollinearity among variables can meet the regression requirements [39]. After the multicollinearity test, the logistic regression results of the model were obtained (Table 4). Next, detailed analysis of the model estimation results was conducted.

Table 3. Multiple collinearity test results of farmers' cost cognition on the enthusiasm of adopting digital agricultural extension services.

Explained Variable	Explanatory Variable	Collinear Statistics	
		Tolerance	VIF
Cost cognition	Gender	0.910	1.10
	Age	0.920	1.09
	Degree of education	0.812	1.23
	Health degree	0.810	1.24
	Agricultural acreage	0.802	1.25
	Labor force proportion	0.947	1.06
	Degree of organization	0.668	1.50
	Virtual variables in Shanxi province	0.394	2.54
	Virtual variables in Shaanxi province	0.377	2.65
	Knowledge and experience	0.426	2.35
	Personal convictions	0.854	1.17
	Emotional attitude	0.615	1.63
	Economic income cognition	0.720	1.39
	Information channel cognition	0.693	1.44
	Financial service support	0.898	1.11
	Technical service support	0.834	1.20
	Legal service support	0.583	1.72
Mean VIF		1.51	

Table 4. The influence of farmers' cognition on the enthusiasm of adopting digital agricultural extension services regression analysis.

	Model (1)			Model (2)		
	Coefficient	Std. Err.	Z	Coefficient	Std. Err.	Z
Subjective cognition						
Knowledge and experience	0.899 ***	0.151	5.95	0.915 ***	0.148	6.18
Personal convictions	0.328 ***	0.116	2.84	0.334 ***	0.115	2.90
Emotional attitude	0.282 ***	0.106	2.67	0.288 ***	0.105	2.74
Objective cognition						
Cost cognition	0.068	0.113	0.61			
Economic income cognition	0.665 ***	0.141	4.73	0.655 ***	0.140	4.67
Information channel cognition	0.120 *	0.114	1.76	0.201 *	0.113	1.78
Control variable						
Gender	−0.609 ***	0.109	−5.64	−0.599 ***	0.107	−5.60
Age	−0.005	0.006	−0.89			
Degree of education	0.050 ***	0.016	3.04	0.053 ***	0.015	3.53
Health condition	0.018	0.108	0.17			
Agricultural acreage	−0.002	0.005	−0.38			
Labor force proportion	0.135	0.218	0.62			
Whether to participate in cooperatives	0.236 *	0.123	1.91	0.243 **	0.123	1.97
Is it in Shanxi?	−0.555 ***	0.177	−3.13	−0.510 ***	0.172	−2.97
Is it in Shaanxi?	0.617 ***	0.194	3.18	0.656 **	0.191	3.44
/cut1	−1.636	0.515		−1.491	0.230	
/cut2	−0.587	0.511		−0.42	0.220	
/cut3	1.185	0.511		1.330	0.221	
/cut4	3.045	0.517		3.188	0.235	
Chi-squared	185.83			184.04		
Pseudo r-squared	0.044			0.044		
Prob > chi2	0.000			0.000		
Log likelihood	−2021.136			−2022.032		
Number of obs.	1475					

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4. Empirical Results Analysis

4.1. Basic Regression Results

Following the multicollinearity test, this study utilized Stata 17.0 to conduct multivariate ordered logit model regression using survey data collected from 1475 farmers. The maximum likelihood estimation method was employed to estimate the parameters, with robust estimation applied for all regressions to control for heteroscedasticity, autocorrelation, and potential outlier influence in the model [40]. Model (1) incorporated all variables, while model (2) built upon model (1) and employed a backward screening method to gradually eliminate insignificant variables until all variables achieved statistical significance at a 10% level. Table 4 presents the regression coefficient, robust standard error, and z-value for each variable.

(1) Farmers' Subjective Cognition:

As depicted in Table 4, whether in Model 1 or Model 2, farmers' personal convictions, knowledge, experience, and emotional attitude within subjective cognition all significantly influence their inclination to use digital agricultural extension services, confirming Hypothesis 1. This implies that farmers, when strengthening their convictions and comprehending the concept and value of digital agricultural extension services, can better assess the potential impact of these services on their agricultural production. Accumulated knowledge and experience further enhance farmers' enthusiasm for adopting digital agricultural extension services. Additionally, a positive emotional attitude toward these services increases farmers' interest and acceptance, boosting their eagerness to utilize digital agricultural extension services. This aligns with the findings of Wang J.X. et al. [7]

(2) Farmers' Objective Cognition:

In farmers' objective cognition, in addition to cost perception, the perception of economic benefits and information channels significantly impacts farmers' enthusiasm for using digital agricultural extension services, validating Hypothesis 2. This suggests that when farmers possess a clear understanding of the actual economic benefits and potential value derived from using digital agricultural extension services, they are more likely to enhance their enthusiasm for adopting these services. Through various information channels accessible via the web or mobile devices, farmers can gain specific and intuitive insights into relevant agricultural information, compensating for conventional agricultural extension service limitations and facilitating digital agricultural extension services adoption. This conclusion aligns with the research results of Gao et al. [1] on new agricultural extension services. Additionally, this article delves into how the interactions between subjective cognitive factors, such as personal beliefs, emotional attitudes, and knowledge experience, and objective cognitive factors such as economic benefit cognition, cost cognition, and information channel cognition, influence farmers' adoption behavior towards digital agricultural extension services. However, due to the length of the document, the authors have placed the results in Appendix A for readers' reference and review. As shown in Appendix A, except for the insignificant interactions in Model 1 and Model 2, the interactions of all other variables have had a significant positive impact on farmers' adoption of digital agricultural extension services. This indicates that the influence is reflected not only in the promotion of farmers' intrinsic motivation and emotional attitudes, but also in the consideration of objective factors such as economic benefits, costs, and information channels. This interplay has jointly propelled farmers' adoption and enthusiasm for digital agricultural extension services.

(3) Influence of Farmers' Individual and Family Characteristics on Adoption Enthusiasm:

Among the control variables, female respondents have a higher enthusiasm for improving the adoption of digital agricultural extension services. The reasons are as follows: Firstly, women tend to have more delicate observation skills and stronger communication abilities. This enables them to deeply understand and grasp the actual benefits brought by digital agricultural extension services when receiving and processing related information.

By more accurately understanding how these services can help agricultural production, female respondents naturally develop a higher enthusiasm for using these services [41]. Secondly, women often play an important role in household decision-making, especially in agricultural production. With the popularization of digital agricultural extension services, female respondents can more actively participate in agricultural production decisions, utilizing these services to improve the efficiency and benefits of agricultural production. This sense of participation and increased decision-making power further enhances their enthusiasm for using digital agricultural extension services [42]. Lastly, female respondents tend to place more emphasis on the harmonious development of families and communities. Digital agricultural extension services can not only help them improve agricultural production levels, but also promote the sharing and dissemination of agricultural knowledge within the community. This enhancement of community awareness makes female respondents more willing to try and accept these new services [43].

In addition, higher levels of education correlate with more vital enthusiasm among farmers to adopt digital agricultural extension services, highlighting the relationship between education and the adoption of these services. When farmers' education levels reach a certain threshold, their enthusiasm for adopting digital agricultural extension services significantly improves. Regarding family characteristics, farmers' participation in cooperatives passed the significance test at a 1% confidence level. This indicates that farmers' involvement in cooperatives and other organizations enhances interpersonal communication, broadens information channels, and boosts their enthusiasm for adopting digital agricultural extension services. These conclusions align with the results of Mao et al. [5] regarding the influencing factors of digital proliferation.

4.2. An Analysis of the Regulatory Role of Policy Incentives

In this study, the sample is categorized into three groups based on the criterion of 'Do farmers believe that there is adequate government financial support, technical support, and legal support?' The groups are 'Farmers Believe in Adequate Support' and 'Farmers Do Not Believe in Adequate Support.' For both groups, this study takes farmers' understanding of the content and methods of digital agricultural extension services as independent variables. The enthusiasm for digital agricultural extension services is considered the dependent variable. Multiple ordered logit regression is conducted accordingly. Coefficients' significant variations in different groups are compared using bootstrap's adjustment effect test to examine the impact of adjustment variables. The regression results are presented in Table 5.

Table 5. Moderating effect of farmers' cognition on the enthusiasm of adopting digital agricultural extension services with policy incentives.

	Financial Service Support		**Technical Service Support**		**Legal Service Support**	
	Model 1 (In Place)	**Model 2 (Not In Place)**	**Model 3 (In Place)**	**Model 4 (Not In Place)**	**Model 5 (In Place)**	**Model 6 (Not In Place)**
Subjective cognition						
Knowledge and experience	0.956 *** (0.160)	0.869 (0.606)	0.910 *** (0.188)	0.923 *** (0.263)	0.913 *** (0.187)	1.191 *** (0.280)
Personal convictions	0.217 * (0.122)	1.194 *** (0.397)	0.502 *** (0.162)	0.129 (0.171)	0.532 *** (0.151)	−0.147 (0.189)
Emotional attitude	0.377 *** (0.114)	0.008 (0.312)	0.355 ** (0.161)	0.242 (0.153)	0.617 *** (0.228)	0.235 (0.152)
Objective cognition						
Cost cognition	0.302 ** (0.123)	−1.092 *** (0.311)	0.295 ** (0.151)	−0.157 (0.173)	0.060 (0.157)	0.092 (0.166)
Economic income cognition	0.647 *** (0.144)	0.837 (0.678)	0.831 *** (0.180)	0.399 * (0.228)	0.571 *** (0.209)	0.798 *** (0.199)
Information channel cognition	0.975 ** (0.396)	0.097 (0.121)	0.322 ** (0.156)	0.308 * (0.184)	0.316 ** (0.160)	0.300 (0.192)
Gender	−0.540 *** (0.118)	−0.151 (0.210)	−0.742 *** (0.149)	−0.425 ** (0.165)	−0.758 *** (0.156)	−0.554 *** (0.026)
Age	−0.005 (0.006)	−0.694 ** (0.334)	−0.013 * (0.008)	0.005 (0.009)	−0.014 * (0.008)	0.004 (0.008)
Degree of education	0.054 *** (0.018)	0.023 (0.046)	0.054 ** (0.022)	0.039 (0.026)	0.047 ** (0.024)	0.052 ** (0.023)
Health condition	0.036 (0.116)	−0.232 (0.329)	−0.185 (0.144)	0.195 (0.166)	−0.135 (0.154)	0.095 (0.157)
Agricultural acreage	−0.001 (0.006)	−0.006 (0.013)	0.007 (0.007)	−0.009 (0.007)	0.008 (0.007)	−0.013 * (0.008)
Labor force proportion	0.121 (0.231)	0.339 (0.697)	0.094 (0.283)	0.243 (0.352)	−0.059 (0.296)	0.250 (0.327)
Whether to participate in cooperatives	0.229 * (0.126)	0.141 (0.633)	0.284 * (0.167)	0.202 (0.189)	0.223 (0.180)	0.302 * (0.172)
Is it in Shanxi?	−0.514 *** (0.183)	−0.744 (1.071)	−0.340 (0.231)	−0.672 ** (0.290)	−0.030 (0.229)	−0.964 *** (0.304)
Is it in Shaanxi?	0.695 *** (0.201)	0.977 (0.885)	1.191 *** (0.252)	−0.107 (0.334)	1.532 *** (0.310)	−0.056 (0.342)

Table 5. *Cont.*

	Financial Service Support		Technical Service Support		Legal Service Support	
	Model 1 (In Place)	**Model 2 (Not In Place)**	**Model 3 (In Place)**	**Model 4 (Not In Place)**	**Model 5 (In Place)**	**Model 6 (Not In Place)**
Chi-squared	185.87	38.09	162.41	55.77	107.28	109.65
Pseudo r-squared	0.050	0.081	0.067	0.031	0.050	0.053
Prob > chi2	0.000	0.000	0.000	0.000	0.000	0.000
Log likelihood	−1768.300	−216.689	−1127.078	−874.710	−1010.453	−986.252
Number of obs.	1287	188	841	634	761	712

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, the standard error is in brackets; this study used Boostrap500 self-help repeated sampling.

(1) Subjective Cognition:

The regression results in Table 5 reveal the following:

Knowledge and experience are not significant in the regression for "farmers perceive as inadequate" in Model 2. However, they are substantial and positive in the regression for "farmers perceive as adequate" in Model 1. This implies a notable positive moderating effect of government financial service support on the relationship between knowledge and experience and farmers' enthusiasm to adopt digital agricultural extension services.

In Models 3, 4, 5, and 6, the regression coefficients and significance for knowledge and experience differ, indicating no significant moderating effect of technical service support and legal service support on the relationship between knowledge and experience and farmers' enthusiasm to adopt digital agricultural extension services.

Personal convictions are not significant in the regressions of Models 4 and 6, but are positive and significant in the regressions of Models 3 and 5. This suggests that both government technical service support and government legal service support have a significant positive moderating effect on the relationship between personal convictions and farmers' enthusiasm to adopt digital agricultural extension services.

Similarly, emotional attitude is not significant in the regressions of Models 2, 4, and 6, but is significant and positive in the regressions of Models 1, 3, and 5. This indicates a notable positive moderating effect of the three policy incentives on the relationship between emotional attitude and farmers' adoption enthusiasm.

(2) Objective Cognition:

Regarding objective cognition:

Cost perception is not significant in the regression of Model 4 but is significant and positive in the regression of Model 3. This indicates a significant positive moderating effect of government technical service support on the relationship between cost perception and farmers' enthusiasm to adopt digital agricultural extension services.

Economic benefit perception is not significant in the regression of Model 2, but is significant and positive in the regression of Model 1. This suggests a significant positive moderating effect of government financial service support on the relationship between economic benefit perception and farmers' adoption enthusiasm.

Information channel perception is not significant in Models 2 and 6, but it is significant and positive in Models 1 and 5. This indicates a significant positive moderating effect of both government financial service support and government legal service support on the relationship between information channel perception and farmers' enthusiasm to adopt digital agricultural extension services. These estimation results partially confirm Hypothesis 3, consistent with the research conclusions of Yu and Yu [44].

(3) Policy incentives:

Government financial service support, government technical service support, and government legal service support are crucial policy approaches to enhance farmers' enthusiasm for adopting digital agricultural extension services. Specifically:

Greater transparency in the allocation and use of agricultural financial funds amplifies farmers' understanding and trust in the policy, thereby strengthening their eagerness to adopt digital agricultural extension services.

Government legal service support, achieved by publishing relevant laws and regulations related to digital agricultural extension services, enhances farmers' cognition of these laws and regulations. The more the government provides legal support services, the stronger the farmers' enthusiasm for adopting digital agricultural extension services.

Technical service measures implemented by the government, such as network training, help farmers grasp agricultural technology. This understanding encourages the application of digital agricultural extension services in agricultural production and daily life, stimulating enthusiasm for adoption. These findings align with the research results of Zhou and Zeng [45].

4.3. Robustness Test

(1) Inspection of Missing Variables

Endogenous issues can introduce biases and inconsistencies in the results of previous analysis. To ensure the robustness of the benchmark regression results, this paper initially addresses measurement errors caused by missing variables and preliminarily discusses endogenous problems.

Most prior regression outcomes only account for provincial fixed effects. Since the research group's questionnaire data for farmers are from 2019 and 2020, we should also consider the potential influence of time-related factors on missing variables, which can lead to biased and inconsistent estimation results. To address these missing variables, this paper follows the approach of Liangand Ji [46] and introduces year-fixed effects while retaining the provincially controlled variables. The coefficient's influence on farmers' cognition and adoption enthusiasm remains significant. Additionally, for farmers to benefit from digital agricultural extension services, their respondents must be connected to the internet, enabling them to access relevant agricultural services through mobile phones or computers. Therefore, this paper includes the variable 'whether families are connected to the internet' while retaining all control variables to test for missing variables (Models 1 and 2 in Table 6). The results indicate that the regression outcomes, after re-evaluating the missing variables, align largely with the previous findings.

Table 6. Robustness test results.

	Regression Results Considering Missing Variables				**Considering the Model Setting Bias**	
	Model 1		**Model 2**		**Model 3**	
	Coefficient	**Std. Err.**	**Coefficient**	**Std. Err.**	**Coefficient**	**Std. Err.**
Subjective cognition						
Knowledge and experience	0.328 ***	0.116	0.358 ***	0.116	0.520 ***	0.086
Personal convictions	0.899 ***	0.151	0.935 ***	0.152	0.184 ***	0.066
Emotional attitude	0.282 ***	0.106	0.308 ***	0.106	0.165 ***	0.061
Objective cognition						
Cost cognition	0.068 *	0.113	0.061	0.113	0.034	0.065
Economic income cognition	0.665 ***	0.141	0.683 ***	0.141	0.376 ***	0.080
Information channel cognition	0.200 ***	0.114	0.174	0.114	0.111 *	0.065
Networking or not			0.602 ***	0.148		
Year control	Controlled					
Control variable	Controlled					
Pseudo R2	0.044		0.048		0.045	
Prob > chil2	0.000		0.000		0.000	
Log likelihood	−2021.136		−2012.808		−2019.484	

Note: *** $p < 0.01$, * $p < 0.1$.

(2) Model Setting Error Test

To address model biases, the study tests the robustness of previous estimation results. The robustness is tested by re-evaluating the model using a multivariate ordered probit model, confirming the influence of farmers' cognition on their adoption enthusiasm. This

verification is essential to ensure the steadfastness of the fundamental findings of this study (Model 3 in Table 6). The estimated results are presented in Table 6. Both the multivariate ordered probit model and the multivariate ordered logit model show a high level of consistency with the estimated results in Table 4. This reaffirms the robustness of the estimated influence of farmers' cognition on their adoption enthusiasm in this chapter.

5. Discussion

The conclusion of this study contributes to a deeper understanding of farmers' behavioral patterns, providing essential theoretical and practical guidance for guiding agricultural production practices and optimizing agricultural extension strategies. This, in turn, facilitates the process of agricultural modernization.

Firstly, farmers' cognition of digital agricultural extension services significantly influences their enthusiasm for adopting these services. This underscores the crucial role of farmers' acceptance of new technologies and knowledge in promoting agricultural extension services. This finding is consistent with the research conducted by Alcardo et al. [8], which emphasizes the importance of farmers' comprehension and grasp of information. Therefore, when promoting digital agricultural extension services, it is essential to enhance farmers' cognitive levels through training and promotion efforts, fostering their understanding and trust in these services.

Secondly, the government, through various support measures such as financial, technical, and legal assistance, actively regulates farmers' cognition and enthusiasm for adopting digital agricultural extension services [15,34]. Financial support measures, such as digital investment subsidies, loans, and tax relief, can directly alleviate the economic pressure faced by farmers when adopting digital agricultural technologies. This reduces the initial investment and operating costs required for farmers to adopt new technologies, thereby stimulating their enthusiasm [35]. Technical support measures, such as digital network training and guidance, enhance farmers' digital literacy and skill levels. This enables them to understand better the principles, operation methods, and potential advantages of digital agricultural technologies. Such skill enhancement boosts farmers' confidence in digital agricultural technologies, promoting their adoption [17,35]. Legal support measures, including legal consultation services, legal supervision, and judicial supervision, provide farmers with legal safeguards and rights protection. These measures address farmers' concerns and safeguard their legitimate rights and interests [47]. This legal protection enhances farmers' trust in digital agricultural extension services, further motivating them to adopt new technologies. The conclusion underscores the government's pivotal role in promoting digital agricultural extension services, echoing the findings of Yu [44] on the role of policy incentives in promoting farmers' adoption of digital technologies.

Moreover, factors such as the gender of respondents, educational level, and membership in cooperatives have a significant positive impact on enthusiasm for adopting digital agricultural extension services. These findings align with the research conducted by Gao et al. [18], indicating the need for targeted strategies that consider the unique characteristics and needs of different farmers when promoting digital agricultural extension services. For instance, gender-specific training and promotion can enhance women's understanding and interest, consistent with the views of Wang et al. [7]. Simplifying technical operations and providing intuitive guides can benefit farmers with lower educational levels, echoing the perspectives of Di Falco et al. [48]. However, factors such as the age of respondents, family farmland area, health status, and the proportion of family labor did not have a significant impact on farmers' enthusiasm for adopting digital agricultural extension services, possibly because they are not decisive factors in farmers' actual production processes [49]. For example, while older farmers may traditionally have a lower acceptance of new technologies, the high level of information technology and popularization in modern society has enabled farmers of all ages to access digital agricultural extension services [14].

Compared to the existing literature, this study not only integrated a multi-dimensional analysis of subjective and objective cognitions, but also focused on innovations in agricul-

tural extension services in the digital era. It explored the impact of farmers' cognitions on the adoption of digital agricultural extension services and further analyzed the moderating role of policy incentives. This not only deepens our understanding of farmers' cognitions and digital agricultural extension services, but also provides a scientific basis for the government to formulate more effective promotion policies. Additionally, this study employed a multivariate ordered logit model and conducted tests for omitted variables and model specification errors. The results indicate that the impact of farmers' cognitions on their enthusiasm for adoption remains significant, demonstrating the robustness and reliability of the conclusions.

However, it must be recognized that popularizing digital agricultural extension services is a protracted and intricate process, requiring collaboration from the government, enterprises, and various societal sectors [50,51]. Additionally, it is worth noting that this study focused solely on a subset of fruit and vegetable farmers in Shandong, Shaanxi, and Shanxi provinces, potentially introducing regional and sample biases in the results. Given the significant differences in economic development levels, cultural backgrounds, and cropping structures across different regions, future research needs to explore further the specific impacts of these regional differences on farmers' cognitions and enthusiasm for adopting digital agricultural extension services. This will facilitate the provision of more targeted and operable recommendations for the regional promotion of digital agricultural extension services, ultimately promoting the more practical application and promotion of digital agricultural technologies in a broader range of areas.

6. Conclusions

Using survey data from 1475 farmers in Shaanxi, Shandong, and Shanxi provinces, this study divided farmers' cognition into subjective and objective dimensions. Using a multivariate ordered logit model, the study analyzed how farmers' cognition affects their enthusiasm for adopting digital agricultural extension services. Additionally, it explored the role of policy incentives as a moderator in this relationship.

The results demonstrate that, aside from cost cognition, farmers' personal convictions, knowledge and experience, emotional attitude cognition, economic benefit cognition, and information channel cognition all significantly and positively impact their enthusiasm for adopting digital agricultural extension services. Currently, government financial service support, technical service support, and legal service support exhibit specific moderating effects on the relationship between farmers' cognition and adoption enthusiasm. Furthermore, among the control variables, having a female head of respondents, a higher education level, and membership in a cooperative all positively influence the enthusiasm for adopting digital agricultural extension services. Importantly, through tests involving missing variables and model transformations, it is evident that the influence of farmers' cognition on the adoption enthusiasm for digital agricultural extension services remains significantly unchanged, confirming the robustness and reliability of the conclusions.

Based on these findings, the paper proposes the following policy recommendations: To facilitate the widespread adoption of digital agricultural extension services, the government should prioritize rural infrastructure development, particularly in ensuring reliable electricity and internet connectivity for farmers. Extensive and targeted promotional activities should be organized to communicate the benefits and values of digital agricultural extension services to farmers, utilizing various means such as advertisements, brochures, and TV and radio programs. Specialized training institutions or projects should be established to provide farmers with technical training and support in digital agricultural extension services, covering aspects such as equipment operation and maintenance, data analysis, and agricultural production management. By offering practical technical training and ongoing support, farmers can overcome barriers to using digital agricultural extension services and enhance their enthusiasm for adoption. Establishing a platform for sharing digital agricultural extension service data and exchanging information can provide farmers with accurate and real-time agricultural information, along with application cases of digital

agricultural extension services, helping them better understand their value and impact. This platform can also offer practical guidance to farmers. Lastly, supporting and strengthening the role of farmers' organizations and cooperatives is vital, making them essential channels for digital agricultural extension services. This can better convey the benefits of these services, ultimately increasing farmers' enthusiasm for adoption.

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Appendix A

Table A1. Regression Analysis of the Influence of Farmers' Subjective and Objective Cognitive Interaction on the Enthusiasm of Adopting digital Agriculture Extension Services.

	Model (1) Coef.	Model (2) Coef.	Model (3) Coef.	Model (4) Coef.	Model (5) Coef.	Model (6) Coef.	Model (7) Coef.	Model (8) Coef.	Model (9) Coef.
Knowledge and experience × Cost cognition	0.337								
	(0.254)								
Personal convictions × Cost cognition		0.187							
		(0.233)							
Emotional attitude × Cost cognition			0.705 ***						
			(0.215)						
Knowledge and experience × C Economic income cognition				0.905 ***					
				(0.328)					
Personal convictions × Economic income cognition					0.591 **				
					(0.258)				
Emotional attitude × Economic income cognition						1.166 ***			
						(0.246)			
Knowledge and experience × Information channel cognition							0.941 ***		
							(0.213)		
Personal convictions × Economic income cognition								0.663 ***	
								(0.227)	
Emotional attitude × Information channel cognition									0.520 **
									(0.213)
Control variable					Controlled				
LR chi2	187.58	186.47	196.60	193.44	191.06	208.38	205.38	194.37	191.79
Pseudo R2	0.044	0.044	0.046	0.046	0.045	0.049	0.049	0.0460	0.045
Prob > chi2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Log likelihood	−2020.258	−2020.813	−2015.751	−2017.329	−2018.522	−2009.858	−2011.358	−2016.867	−2018.155
Number of obs.					1475				

Note: *** $p < 0.01$, ** $p < 0.05$. The numbers in parentheses represent standard errors.

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