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Effectiveness of Information Acquisition via the Internet in Standardizing the Use of Antimicrobials by Hog Farmers: Insights from China

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Abstract: Antimicrobial residues and resistance caused by farmers' overuse of veterinary antimicrobials have seriously threatened food safety, the ecological environment, and public health. With the popularization of the Internet in rural areas, especially in developing countries, the constraints of obtaining agricultural technical information provided by governments or organizations are greatly eased, farmers' knowledge and skills are significantly improved, and the agricultural standardized production system is effectively constructed. However, there is still a research gap on whether information acquisition via the Internet (IAI) can induce farmers to standardize the use of antimicrobials. Using the data of 675 hog farmers in the Hebei, Shandong, Henan, and Hubei provinces, China, the IV-Heckman and mediating effect models were used to analyze the phenomenon empirically. The main findings revealed that the IAI had exerted a significant influence on the standardized use of veterinary antimicrobials by hog farmers, i.e., the IAI not only helped farmers to decide to standardize the use of antimicrobials but also reduced the amount of investment in the standardized use of antibiotics. Moreover, information-sharing and feedback mechanisms partially mediated the relationship between the IAI and farmers' standardized use of antimicrobials. Finally, considering the heterogeneity of individual endowments, the study further revealed that the IAI significantly impacted the standardized use of antimicrobials for farmers below the age of 36 years. However, the IAI was found to positively and significantly promote farmers' standardized-use decisions only if they had less than five years of breeding time.

Keywords: IAI; veterinary antimicrobials; standardized use; IV-Heckman model; China

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1. Introduction

Since the 1950s, veterinary antimicrobials have been playing an irreplaceable role in reducing livestock morbidity and mortality, promoting livestock growth, and improving the quality of meat products. As people's consumption of meat increases, it is predicted that the use of antimicrobials will also increase globally by 67% in 2030 [1]. However, the overuse and residue of antimicrobials make bacterial microorganisms gradually express resistance characteristics [2]. There are complex transmission routes of antimicrobial resistance between livestock and humans, especially antimicrobials that can re-enter agroecosystems through animal manure, biosolids, and groundwater [3]. Moreover, pathogenic and symbiotic microorganisms in the ecological environment can also transfer to humans directly through contact and food intake [4–6].

Farmers are users of antimicrobials in livestock production and are directly responsible for the standardized use of antimicrobials. The standardized use of antimicrobials is closely related to disease type, breeding techniques, experience, and veterinary services and is a fluctuating veterinary technical standard [7]. Some studies have demonstrated that the standardized use of antimicrobials is characterized primarily by recommended doses prescribed by veterinarians (prescription antimicrobials) or doses specified in package inserts (over-the-counter antimicrobials) [8]. Specifically, there are significant differences in veterinary experience or skill level. A veterinarian with a high degree of expertise may also be more effective in administering a prescription of antimicrobial for the same disease. In contrast, a veterinarian with poor technologies may need multiple trials and errors to achieve the same effect. Therefore, in many developing countries where veterinary technology lags, although the dosage of antibiotics is still in line with the standardized use of antimicrobials, the standardized dosage of antibiotics is generally at a high level. In addition, farmers have greater operability in the selection and use of over-the-counter antimicrobials, and they are always at greater risk of non-standardized use of over-the-counter antimicrobials under disease stress or loss [9].

The final decision-makers in the value chain of the animal health system, breeders' production decisions are largely influenced by the practices and demands of other actors in the system [10,11]. The main core strategy of guiding the standardized use of antimicrobials and promoting its development towards "no-antimicrobials" is to enhance the cooperation between breeders and other actors such as the government, butchers, processors, and consumers and to realize the circulation of antimicrobials use information in the whole industrial chain [12,13]. Previous studies have found that the government, as the most powerful external stakeholder, can define illegal behaviors through coercive measures to force farmers to standardize the use of antibiotics, or it can use non-coercive means to change the external environment of farmers' safety production, encouraging and guiding them towards standardized use of antimicrobials [11,14–16]. However, information asymmetry may increase the gap between the intended objectives and implementation outcomes of mandatory and non-mandatory policy instruments and even promote the emergence of illicit markets in the non-standardized use of antimicrobials [13]. In addition, many kinds of literature also discussed the factors affecting the use of antibiotics by farmers, including individual characteristics such as gender, age, and education level [17,18]; cognitive characteristics such as risk perception, risk cognition, and risk preference [19]; operational characteristics such as breeding scale, breeding years, breeding mode, organizational participation, and biosafety measures [20,21]; social factors such as relationship network, individual norms, and contractual governance; as well as various policy measures [22–24].

According to the Statistical Report on China's Internet Development, as of June 2022, the Internet penetration rate in China's rural areas reached 58.8%, an increase of 1.2 percentage points over December 2021. Of course, due to many kinds of factors such as terrain characteristics, population density, and service quality, the Internet broadband speed in some rural areas is very slow. Moreover, with the implementation of China's modern agricultural strategy, the Internet has become an essential learning medium for the government or organizations to promote agricultural technology and farmers to obtain the latest agricultural information. Therefore, the information acquisition via the Internet (IAI) in this article mainly refers to farmers' access to information on standardized use of antimicrobials provided by governments or organizations through the Internet. Specifically, the government or organization carries out online technical training, online video exhibition, and solving difficult problems through Internet means, with the purpose of improving farmers' knowledge or skills concerning the standardized use of antimicrobials. Thus, IAI requires farmers to access the standardized use of antibiotics through the Internet. Unfortunately, previous research has not paid much attention to the role of the IAI in standardizing the use of antimicrobials by farmers.

The main objective of the research is to empirically analyze the influence of the IAI on the standardized use of antimicrobials by farmers and its induction mechanism by using the survey data of 675 hog farmers in the Hebei, Henan, Shandong, and Hubei provinces, China. The current study contributes to the literature in the following ways: firstly, the study innovatively defines the concept and measurement criteria for farmers' standardized use of antimicrobials. Secondly, considering the sample selection bias caused by farmers' standardized use decisions and endogeneity caused by missing variables and reverse causality, the IV-Heckman and the mediating effect models are employed to empirically analyze the promoting effect of the IAI on the standardized use of antimicrobials by farmers and its induction mechanism. Finally, considering the heterogeneity of individual endowments, the study further explores the phenomenon by considering the group differences in the IAI's effects. The overall findings may provide an essential reference for the government to promote farmers' standardized use of veterinary antimicrobials accurately.

The rest of the paper is organized as follows. The second provides the theoretical analysis and research hypothesis. The third part presents data sources and research methods. The fourth part reports the model results and discussion. Finally, conclusions are presented in the last section.

2. Theoretical Analysis and Research Hypothesis

Firstly, the IAI affects farmers' standardized use of antimicrobials through the information supply mechanism. Information constraint is a bottleneck for farmers' safe production in developing countries [25]. Previous studies have confirmed that the farmers' main reason for the overuse of antimicrobials is the lack of medication skills or knowledge [8]. Additionally, the situation is exacerbated by the inadequate supply of veterinary services in rural areas [26]. Through the timely transmission and acquisition of information, the IAI has changed the original channels of information transmission and significantly reduced the cost of government information supply and farmers' information acquisition through the reconfiguration of technology, labor, and capital production factors [27]. Furthermore, the IAI has also changed the supply mode of government information services, updated the original medication knowledge of farmers, improved their cognition of standardized use, and actively guided them to engage in the standardized use of antimicrobials. Hence, hypothesis H1 is proposed.

H1. *The IAI is beneficial to standardize the use of antimicrobials by farmers through the information supply mechanism.*

Secondly, the Internet promotes farmers' standardized use of antimicrobials through the information-sharing mechanism. Through low communication costs, the IAI has changed farmers' original social capital accumulation [28]. Most farmers choose the decentralized breeding mode to reduce the infection rate of livestock disease. However, due to the popularization of the Internet, geographical distance has not changed the strength of the relationship network among farmers [29]. Government training in the practical skills of antimicrobial use is often aimed at targeting specific groups, such as companies, cooperatives, or large farmers. The IAI can realize information sharing between the initial information recipients, such as cooperative organization and other small farmers, and accelerate the rapid dissemination of information or skills [30,31]; reduce the government's cost of agricultural technology promotion; and improve the standardized use of antimicrobials. In addition, the IAI is also likely to accelerate the spread of standardized antimicrobial use technology among farmers through the peer effect, finally forming the imitation and learning effect of standardized antimicrobial use technology. So, hypothesis H2 is given.

H2. *The IAI significantly influences farmers' standardized use of antimicrobials through the information-sharing mechanism.*

Lastly, the IAI guides the farmers to standardize antimicrobials through the information feedback mechanism. The industrial chain system and the food traceability system built by the Internet are the two pillars for constructing a modern food safety system. Especially on the one hand, integrating the industrial chain is an essential part of constructing modern agricultural and industrial systems [32,33]. The Internet can strengthen the links among the stakeholders in the industrial chain, such as producers, butchers, processors, and sellers, who timely communicate market information such as market price, product quality, and consumer demand [34,35]. Effective market information reduces information asymmetry in the industrial chain, and stakeholders adjust their production decisions in time [36,37]. On the other hand, many countries have set up food traceability systems via the Internet. The antimicrobial residue is key to meat-derived food safety detection [38,39]. Once veterinary antimicrobials' residues exceed the slaughter, processing, or distribution limit, the traceability system pushes the related information to the target farmers. Meanwhile, liability traceability can also restrain farmers from overusing antimicrobials. Therefore, hypothesis H3 is proposed in this paper. The theoretical framework used in the current study is shown in Figure 1.

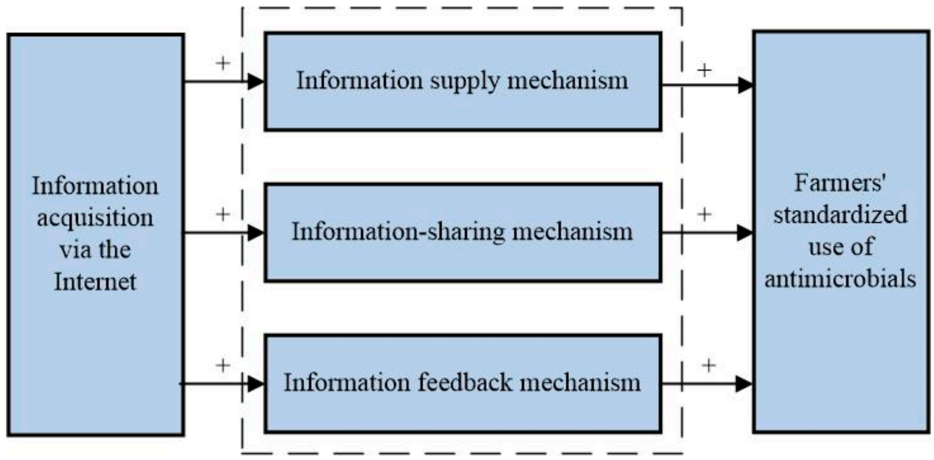

Figure 1. The theoretical framework used in the current study.

H3. *The IAI significantly influences farmers' standardized use of antimicrobials through the information feedback mechanism.*

3. Data and Methods

3.1. Data Source

The data used in this study were obtained from a field survey of hog farmers from the Hebei, Shandong, Henan, and Hubei provinces, China, from July to September 2021. The main reason for selecting sample areas was that the breeding scales in Hebei, Shandong, Henan, and Hubei were 18.101 million, 31.51 million, 43.92 million, and 25.301 million hogs, respectively, in 2020. Meanwhile, the breeding density was large, the incidence of bacterial infectious diseases was high, and the use of antimicrobials was large. The main contents of the questionnaire survey also included individual characteristics, family characteristics, operation and management, antimicrobials use, Internet use, policy measures, etc. A combination of stratified and random samplings was employed for a questionnaire survey. Specifically, five counties were chosen from each province, two–four towns were randomly selected, and 12–16 farmers were randomly selected from each village. About 750 questionnaires were distributed, 75 invalid samples were excluded, and 675 valid samples were selected for empirical analysis, with an effective sample rate of 96.70%. The sampled households from Hebei, Henan, Hubei, and Shandong were 168, 182, 177, and 148, accounting for 24.8%, 26.9%, 26.2%, and 21.9%, respectively.

Table 1 shows the basic characteristics of sampled households' heads. The households' heads were mainly male, accounting for 73.4%, and female farmers occupied a secondary position in family breeding decisions. Male laborers accounted for more than 60% of the total family laborers. The farmers were mainly middle-aged people, 36–60 years old, accounting for 62.52%, and the family laborers' age structure was reasonable. The education time was short, among which primary school (0–6 years) accounted for 41.93%, and middle school accounted for 33.93%. The breeding time was mainly 5–15 years, accounting for

62.37%, indicating that the surveyed farmers had good breeding experience. In addition, most of the family's breeding scale was less than 150 heads, accounting for 60.59%, showing that the sampled area held mainly medium- and small-scale breeding.

Table 1. Basic characteristics of sample farmers.

Variables	Classification	Ratio %
Gender	Male	73.4%
	Female	26.5%
Age	<36 years	3.85%
	36–60	62.52%
	>60	33.63%
Educational time	0–6 years	41.93%
	7–9	33.93%
	10–12	10.22%
	>12	0.59%
Breeding time	<5 years	25.63%
	5–15	62.37%
	>15	12.00%
Breeding scale	<150 heads	60.59%
	150–300	24.30%
	>300	15.11%
Male laborers	<0.3	1.33%
	0.3–0.6	22.67%
	>0.6	76.00%

3.2. Variable Selection

3.2.1. Dependent Variable

The dependent variable in the current study was farmers' standardized use of antimicrobials, which was measured by the decisions and the degree of standardized use by farmers. On the one hand, questions in the questionnaire included "Did you use the recommended dosage of the veterinary prescription (prescription antimicrobials) or the package Insert (over-the-counter antimicrobials)?" to measure the decisions of standardized use by farmers. If the farmer chose the standardized use, the value was 1; otherwise, the value was 0. On the other hand, the degree of antimicrobial use by farmers was expressed by the amount of investment in the standardized use of antibiotics. Due to the different types, preparations, concentrations, and packages of antimicrobials, the number of antimicrobials used could not be directly summed up in milliliters or grams. Sun and Zhou's [40] studies used the payment amount of antimicrobials to calculate the number of antimicrobials. In addition, to eliminate individual differences brought by the breeding scale, the "degree of the standardized use" was measured by the "ratio of the payment amount of standardized use of antimicrobials to the number of hogs", and it was a continuous variable.

3.2.2. Independent Variable

The core explanatory variable was the IAI. The development of modern communication technology, represented by the Internet, could broaden farmers' access to information, reduce the cost of information acquisition, and reduce the asymmetry of market information, thus affecting farmers' production safety decisions [41,42]. Meanwhile, the Internet was an important medium or platform for animal husbandry, cooperative organizations, or veterinarians to provide disease diagnosis and antimicrobial use services. Therefore, "Had you obtained the knowledge of veterinary antimicrobial use through the Internet?" in the questionnaire was set to determine whether farmers used the Internet as a primary channel for searching and acquiring antimicrobial knowledge or skills. The IAI was a discrete binary variable. Those who used the Internet to acquire antimicrobial use knowledge or skills were assigned a value of 1; otherwise, 0 was assigned. About 41.77% of farmers in the sample area searched for antimicrobial knowledge or skills through mobile the Internet.

3.2.3. Control Variables

Referring to the studies of Liu et al. [43], Si et al. [44], and Xu et al. [45], this paper also selected gender, age, education level, organizational participation, peer effect, breeding time, family laborers, transaction mode, and breeding mode as control variables. Meanwhile, regional dummy variables "Were you in Henan?", "Were you in Shandong?", and "Were you in Hebei?" were added, and, according to the principle of random extraction, Hubei was regarded as the control group. According to the descriptive statistical analysis and independent sample *T*-test in Table 2, it was found that there was a significant mean difference between the control variables of the IAI group and the non-IAI group. The differences of the decision and degree of standardized use between the IAI group and the non-IAI group were statistically significant at 1%, with a mean difference of −0.113 and −0.411, respectively. Meanwhile, the differences of age, family laborers, and transaction mode between the IAI group and the non-IAI group was statistically significant, with mean differences of 1.830, 0.283, and 0.183, respectively. In addition, the mean value of different groups in Hebei province had a significant difference of −0.084 at the statistical level of 5%.

Table 2. Descriptive statistical analysis of variables.

Variables	Variable Assignment	Sample Mean		Mean Difference (A − B)
		IAI Group (A)	Non-IAI Group (B)	
The decision of standardized use	Standardized use = 1, non-standardized use = 0	0.326	0.213	−0.113 ***
Degree of standardized use	The ratio of the payment amount for standardized use of antimicrobials to the number of hogs	12.536	12.125	−0.411 ***
Internet	Have you obtained knowledge of veterinary antimicrobial use through a mobile phone or computer? (Yes = 1, no = 0)	——	——	——
Gender	Male = 1, female = 0	0.716	0.748	0.032
Age	Actual age (year)	54.819	56.649	1.830 **
Educational time	Actual educational time (year)	5.965	5.941	−0.023
Organizational participation	Joining = 1, non-joining = 0	0.564	0.601	0.037
Peer effect	Is your standardized use of antimicrobials influenced by the behavior of other farmers? (No effect at all = 1—very significant effect = 5)	3.486	3.422	−0.063
Breeding time	Time spent breeding hogs (year)	8.535	8.608	0.073
Family laborers	Actual family laborers (people)	2.972	3.254	0.283 *
Transaction mode	Vertical order transaction = 1, loose market transaction = 0	0.227	0.410	0.183 ***
Breeding mode	Cooperative, family farm or company breeding = 1, small family breeding = 0	0.439	0.401	0.038
Were you in Henan?	Yes = 1, no = 0	0.280	0.255	0.025
Were you in Shandong?	Yes = 1, no = 0	0.234	0.199	0.036
Were you in Hebei?	Yes = 1, no = 0	0.214	0.298	−0.084 **

Note: *, **, and *** represent the significance levels of 10%, 5%, and 1%, respectively; robust standard error is in parentheses.

3.3. Model Setting

3.3.1. IV-Heckman Model

The issues of sample selection caused by farmers' standardized use decisions and the endogeneity caused by the missing variables and reverse causality should be dealt with well to analyze the influence of the IAI on farmers' standardized use of veterinary antimicrobials. The standardized use of antimicrobials could be divided into two independent and interrelated stages: the decision and the degree of veterinary antimicrobials use. Due to some factors such as risk perception, disease pressure, and expected loss, some farmers did not choose the standardized use of antimicrobials, so the degree of standardized use could not be observed. Thus, the sample of farmers' standardized use degree was the sample selected. Moreover, in addition to control variables, some missing variables might affect both dependent and independent variables, thus generating endogeneity issues. The farmers' need for standardized antimicrobial use techniques would also increase their options for the IAI. Hence, there was a reverse causal relationship between the IAI and farmers' standardized use of antimicrobials. By referring to Guo et al.'s [43] studies, the IV-Heckman model was adopted to overcome both sample selection and endogeneity issues. This study selected the "number of mobile phone contacts" as the tool variable. On the one hand, farmers with more mobile phone contacts were likely to access the Internet more often, thus obtaining more antimicrobial use knowledge through the Internet. On the other hand, the number of mobile phone contacts did not directly correlate with farmers' standardized use of antimicrobials, which satisfied the condition of the exogeneity of an instrumental variable.

Thus, the IV-Heckman model was divided into two stages: in the first stage, the endogenous explanatory variable "IAI" was linear regression to instrumental variables and all exogenous explanatory variables, and the potential variable fitting value of the IAI was obtained. In the second stage, the Heckman model estimated the decision and the degree of standardized use. Specifically, the first step was to establish an equation to analyze the decision of farmers' standardized use (selection equation). The equation was expressed as follows:

$$\text{Probit}(decision_i) = \alpha_1 + \beta_1 IAI^* + \gamma X + \varepsilon_i \tag{1}$$

where IAI^* was the latent variable of the Internet, and $decision_i$ signified farmers' standardized use decisions. If farmers decided to standardize the use of antimicrobials, the value was 1; otherwise, the value was 0. X was control variables, ε_i was the random error term, and α_1, β_1 and γ were the estimated values of the parameter.

Meanwhile, the IV-Heckman model required that at least one variable should be included in the first stage selection equation but not in the result equation of the second stage. Therefore, "the distance between the farmers and the veterinary service station" was the identification variable. The closer the farmers were to the veterinary service station, the higher the probability of the decision to use standardized. Still, there was no direct causal relationship between the identification variable and the degree of standardized use by farmers. In addition, to correct the sample selection issue caused by the farmer's decision, the Inverse Mills Ratio (IMR) of the farmer's sample should be estimated.

So, the second step was constructed to analyze the degree of standardized use by farmers (the result equation). OLS regression was performed for the fitting value of the latent variables "IAI", residual, inverse mills-ratio, and control variables against the degree of standardized use by farmers, and the equation was expressed as follows:

$$Degree = \alpha_2 + \beta_2 IAI^* + \gamma Z + \varepsilon_i \tag{2}$$

where *Degree* signified the degree of standardized use by farmers, Z indicated the vector of the control variables, γ was the coefficient to be estimated, ε_i represented the random error term, and β_2 was the estimator after overcoming the issues of sample selection and endogeneity. In addition, the significance of IMR values could be used to determine whether there was a sample selection issue.

To compare the estimation results that only considered endogeneity or sample selection, the following estimates were also made in the current study: (1) IV-probit model and two-stage least square method (2SLS) were used separately to estimate the decision and the degree of farmers' standardized use of antimicrobials, and only the endogeneity issue was fixed. The findings were illustrated in regression 1 and regression 2 (see Table 3). (2) The Heckman two-stage model was also used to estimate the decision and the degree of antimicrobials standardized use, and the issue of sample selection was considered. The regression results were illustrated in regressions 3 and 4. (3) The IV-Heckman model was also employed to analyze the effectiveness of the IAI in standardizing the use of antimicrobials by farmers, and sample selection and endogeneity issues were considered simultaneously. The results were shown in regression 5 and 6.

Table 3. Estimates of the impact of the Internet on the standardized use of antimicrobials by farmers.

Variables	Regression 1	Regression 2	Regression 3	Regression 4	Regression 5	Regression 6
	Decision	Degree	Decision	Degree	Decision	Degree
	IV-Probit	2SLS	Heckman		IV-Heckman	
IAI	0.272 *** (0.092)	−0.104 * (0.060)	0.332 *** (0.113)	−0.301 * (0.171)	0.335 *** (0.114)	−0.372 ** (0.169)
Gender	−0.054 (0.094)	−0.081 (0.186)	0.024 (0.122)	−0.036 (0.165)	0.027 (0.139)	−0.012 (0.163)
Age	−0.009 ** (0.003)	−0.013 * (0.007)	−0.003 (0.004)	0.000 (0.007)	−0.003 (0.005)	−0.001 (0.007)
Educational time	0.009 (0.010)	0.017 (0.020)	0.013 (0.014)	−0.005 (0.026)	0.013 (0.055)	−0.001 (0.022)
Organizational participation	−0.013 (0.09)	0.378 ** (0.019)	−0.022 ** (0.011)	0.002 (0.036)	−0.023 ** (0.011)	−0.012 (0.020)
Peer effect	−0.026 (0.024)	−0.066 (0.051)	−0.022 (0.028)	−0.050 (0.052)	0.021 (0.031)	−0.046 (0.042)
Breeding time	0.089 (0.085)	−0. 110 (0.165)	0.078 (0.108)	−0.063 (0.187)	0.076 (0.115)	−0.002 *** (0.159)
Family laborers	0.011 (0.033)	0.002 (0.067)	0.004 (0.041)	−0.013 (0.057)	0.005 (0.045)	−0.029 (0.056)
Transaction mode	0.018 * (0.108)	−0.139 (0.234)	0.435 *** (0.112)	−0.229 (0.629)	0.433 *** (0.125)	−0.130 (0.337)
Breeding mode	0.119 *** (0.031)	−0.265 *** (0.055)	0.227 *** (0.037)	−0.068 (0.326)	0.228 *** (0.037)	−0.074 (0.178)
Were you in Henan?	−0.057 (0.121)	−0.327 (0.259)	−0.154 (0.154)	−0.131 (0.317)	−0.155 (0.166)	−0.117 (0.078)
Were you in Shandong?	−0.032 (0.128)	−0.527 ** (0.260)	0.045 (0.158)	−0.537 ** (0.239)	0.051 (0.169)	−0.587 *** (0.175)
Were you in Hebei?	0.027 ** (0.121)	0.104 (0.252)	0.136 (0.156)	−0.352 (0.029)	0.135 (0.161)	0.000 (0.000)
Distance between the enclosure and the veterinary service station	——	——	0.120 *** (0.043)	——	0.121 *** (0.043)	——
IMR value	——	——	8.25 ***		8.12 ***	
DWH test value	23.14 **	20.69 **	——		18.25 **	
The T value of the tool variable	5.12 ***	5.29 ***	——		5.25 ***	
F value in stage one	121.56	102.56	——		229.5	

Note: *, **, and *** represent the significance levels of 10%, 5%, and 1%, respectively; robust standard error is in parentheses.

3.3.2. Mediating Method

The mediating model was used to verify the induction mechanisms of information supply, sharing, and feedback mechanisms on the IAI influencing farmers' standardized use of antimicrobials. The specific test was carried out in two stages. In the first stage, the influence of the IAI on mediating variables was tested, and the endogeneity of the IAI also needed to be overcome. Therefore, this study constructed model estimation based on the two-stage least square method (2SLS), and the equation was expressed as follows:

$$Media_i = \alpha_3 + \beta_3 IAI^* + \gamma X + \varepsilon_i \tag{3}$$

where $Media_i$ was the mediating variables, namely, information supply, sharing, and feedback mechanisms, which were, respectively, used as "quality evaluation of antimicrobials use information or technology provided by animal husbandry department (very poor = 1—very good = 5)", "quality evaluation of antimicrobials use information or technology obtained by other farmers? (Very poor = 1—very good = 5)", and "the influence of stakeholder's information feedback on farmers' antimicrobial use (very weak = 1—very strong = 5)". Z represented the vector of control variables, ε_i was the random error term, α_3, β_3, and γ was the estimated values of the parameters, respectively.

$$\text{Probit}(decision_i = 1) = \alpha_4 + \beta_4 IAI^* + \beta_5 Media_i + \gamma X + \varepsilon_i \tag{4}$$

$$Degree_i = \alpha_5 + \beta_6 IAI^* + \beta_7 Media + \gamma Z + \varepsilon_i \tag{5}$$

where $\text{Probit}(decision_i = 1)$ was the probability of farmers' standardized use decision, $Degree_i$ was the degree of farmers standardizing the use of antimicrobials, and α_4, α_5, $\beta_4 \sim \beta_7$, and γ were the estimated values of the parameters, respectively. The specific testing process of mediating effect was drawn from the study of Wen et al. [46] and Sun et al. [47].

4. Results and Discussion

4.1. Influence of the Internet on the Standardized Use of Antimicrobials by Farmers

Considering the multicollinearity issue that might exist between multiple variables, a multicollinearity test was conducted on the respective variables, and the test results showed that the maximum value of variance inflation factor (VIF) was 1.77, less than the critical value of 10. Thus, it was considered that there was no multicollinearity issue. Additionally, the Wald value for the IV-Heckman model's overall goodness of fit was 54.98, statistically significant at the 1% level. Therefore, the overall fitting degree of the IV-Heckman model was good, indicating that the model selection was reasonable and feasible. According to regression 1 and 2, DWH test values were found statistically significant at the 5% level, indicating an endogeneity issue caused by missing variables and reverse causation. The F values of the first stage were 121.56 and 102.56, respectively, larger than the critical value 10, indicating that the instrumental variables passed the weak instrumental variable test. The T values of the instrumental variables were all statistically significant at 1%, indicating that the variable "number of mobile phones contacts" could be used as the instrumental variable, and the model estimation results were valid. According to regression 3 and regression 4, the IMR value was statistically significant at the 1% level, indicating that the degree of standardized use of antimicrobials by farmers resulted in sample selection bias. According to regression 5 and regression 6, the T value of the instrumental variable and IMR value of sample selection bias was statistically significant at 1%, and the identification variable "distance between farmers and veterinary service station" was also statistically significant at 1%, indicating that the estimation results of IV-Heckman model were effective.

The results of regressions 1, 3, and 5 showed that the coefficients of the IAI were all positive, which had a positive and significant influence on farmers' decisions of standardized use of antimicrobials. According to regression 5, after overcoming the endogeneity and sample selection issues, the coefficient values of the IAI were greater than the estimated results of regressions 1 and 3, suggesting that missing variables and reverse causation did affect farmers' decisions of standardized uses of antimicrobials, i.e.,, the IV-Heckman model was more appropriate. Regressions 5 and 6 results showed that the IAI significantly and positively influenced farmers' decisions to standardize antimicrobials at the 1% statistical level. In comparison, the IAI significantly and negatively impacted farmers' degree of standardized use of antimicrobials at a 5% significance level. This suggested that the IAI could improve the probability of farmers' decisions to standardize antimicrobials and reduce the payment amount for the standardized use of antimicrobials, which was consistent with Talanow et al.'s study [48]. Especially, farmers could continuously improve their skills in the standardized use of antimicrobials through the IAI to obtain skills training on the use of antimicrobials, video lectures on Internet platforms, and timely responses on challenging issues by animal husbandry departments or cooperative organizations [49]. However, other scholars had also pointed out that the IAI was an essential channel for farmers to obtain veterinary antibiotics illegally, and information on antibiotic use obtained through the IAI was unofficial or false sometimes [50–52]. Therefore, the IAI was beneficial to encourage farmers' standardized use of antimicrobials but needed to be strongly supervised by the government.

Some control variables were also found to influence the farmers' decisions and the degree of standardized use of antimicrobials. Specially, breeding time had a significant negative influence on farmers' decisions on the standardized use of antimicrobials, which supported the research conclusion of Lekagul et al. [53] and Zhong [54]. The longer the breeding time, the stronger the empirical dependence. Farmers often used antimicrobials based on experience and neglected to adopt standardized antibiotic techniques [55]. Meanwhile, the empirical results were consistent with those of Zheng et al. [56] and Nie et al. [57], arguing that breeding and transaction modes significantly impacted farmers' standardized use of antimicrobials. On the one hand, in the vertical trading mode, the regular trading partners had enough market incentives, such as possible epidemic risk, price risk, and market premium, to strengthen farmers' supervision and strictly control pork quality. On the other hand, compared with small-family breeding, cooperative, family farming or company farming had a higher degree of scale and standardization, better biosafety measures, lower incidences of disease, and were more inclined to standardized use of antimicrobials. In addition, our study confirmed that organizational participation had a significant negative effect on the degree of standardized use of antimicrobials by farmers. Cooperative organizations influenced farmers' safe production behaviors through technical service supply, safe production management, and unified product sales [58,59].

4.2. Empirical Analysis of Induction Mechanism

4.2.1. Test Results of the Information Supply Mechanism

The test results of the information supply mechanism's mediating effect are shown in Table 4 (regression 7–9). According to regression 5 in Table 3, the IAI had a positive and significant influence on farmers' decisions of standardized the use of antimicrobials at the significance level of 1%, with a coefficient of 0.335, which was the total effect of the IAI. According to regression 7 in Table 4, after adding the mediating variable "information supply mechanism," the IAI was found to have a positive and significant influence on farmers' decisions to standardize the use of antimicrobials, but the influence coefficient decreased. Moreover, according to regression 8, the information supply mechanism positively and insignificantly influenced farmers' standardized use decisions. Hence, it was necessary to conduct the Sobel test to verify the significance of the information supply mechanism. The test results showed that the Z-value of the Sobel test was 0.317 (lower than the critical value of 0.97), indicating that the information supply mechanism's mediating effect was insignificant. Additionally, according to regression 9, the information supply mechanism had a positive and insignificant effect on the degree of standardized use of antimicrobials by farmers, and the Sobel test value was 0.328 (lower than the critical value of 0.97). Therefore, the mediating effect of the information supply mechanism concerning the influence of the IAI on farmers' standardized use decisions and the degree were not significant, which was contrary to Si et al.'s [60] study, and hence H1 was falsified. Possible explanations were that the information supply of the animal husbandry sector was an important source for farmers to obtain new technology or information on standardized the use of antimicrobials. However, their information supply also had many real issues, such as low technical training frequency, low service quality, and weak timeliness [61]. Thus, the livestock sector's information supply had not improved the information or skill constraints experienced by farmers in standardizing the use of antimicrobials.

4.2.2. Test Results of the Information-Sharing Mechanism

The mediating effect test results of the information-sharing mechanism were shown in regression 10–12. According to regression 10, the IAI positively promoted the information-sharing mechanism at the significance level of 10%, with a coefficient of 1.190. According to regression 11, after adding the variable "information-sharing mechanism", the IAI positively and significantly influenced farmers' standardized use decisions. Meanwhile, the information-sharing mechanism positively affected farmers' standardized use decisions at the significance level of 5%, and the coefficient was 0.123. Thus, the information-sharing mechanism had a partial mediating effect on the influence of the IAI on farmers' standardized use decisions of antimicrobials, and the mediating effect was 0.146 (1.119×0.123), accounting for 43.69% (0.146/0.335) of the total effect.

Similarly, the IAI had a significant negative influence on the degree of standardized use by farmers at the statistical level of 5%, and the coefficient was −0.372, i.e., the total effect was −0.372. After adding the variable "information-sharing mechanism", the IAI significantly and negatively impacted the degree of standardized use at the significance level of 1%. Meanwhile, the information-sharing mechanism negatively affected the degree of standardized use by farmers at the significance level of 1%, and the coefficient was −0.089. According to regression 10, the IAI positively impacted the information-sharing mechanism at the statistical level of 10%, with a coefficient of 0.190. The information-sharing mechanism had a partial mediating effect on the influence of the IAI on the degree of the standardized use of antimicrobials by farmers, and the mediating effect was −0.106 (0.190×0.089), accounting for 28.47% (−0.016/0.372) of the total effect. To sum up, the IAI positively and significantly affected farmers' decisions and degrees of standardized use of antimicrobials through the information-sharing mechanism, which was consistent with Si et al. [44], and thus H2 was confirmed. It might have to be explained as follows. The IAI reshaped the network structure of farmers through employment channel selection and labor transfer [62]. Suppose the information on antimicrobial use skills provided by the livestock sector was transmitted to farmers. In that case, the information would spread to other farmers and form a peer effect through the new relationship network formed by the IAI.

4.2.3. Test Results of the Information Feedback Mechanism

The mediating effect test results of the information feedback mechanism were shown in regression 13–15. According to regression 13, the IAI had a positive promoting effect on the information feedback mechanism at the significance level of 5%, and the influence coefficient was 1.170. According to regression 14, after adding the variable "information feedback mechanism", the IAI positively and significantly impacted farmers' standardized use decisions at the statistical level of 1%. Meanwhile, the information feedback mechanism positively impacted farmers' standardized use decisions at the significance level of 1%, with a coefficient of 0.062. The information feedback mechanism showed a partial mediating effect in the influence of the Internet on farmers' decisions on standardized use of antimicrobials, and the mediating effect was 0.073 (1.170×0.062), accounting for 21.65% (0.073/0.335) of the total effect.

Table 4. Results of mediating effect test.

Variables	Regression 7	Regression 8	Regression 9	Regression 10	Regression 11	Regression 12	Regression 13	Regression 14	Regression 15
	Information Supply Mechanism	**Decision**	**Degree**	**Information-Sharing Mechanism**	**Decision**	**Degree**	**Information Feedback Mechanism**	**Decision**	**Degree**
IAI	1.287 ** (0.570)	0.334 *** (0.114)	−0.201 *** (0.021)	1.190 * (0.661)	0.331 *** (0.114)	−0.201 *** (0.032)	1.170 ** (0.303)	0.322 *** (0.115)	−0.160 *** (0.023)
Information supply mechanism	— —	0.017 (0.020)	−0.014 (0.030)	— —	— —	— —	— —	— —	— —
Information-sharing mechanism	— —	— —	— —	— —	0.123 ** (0.058)	−0.089 *** (0.019)	— —	— —	— —
Information feedback mechanism	— —	— —	— —	— —	— —	— —	— —	0.062 *** (0.021)	−0.069 *** (0.019)
Control variables	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Sample size	675	675	188	675	675	188	675	675	188

Note: *, **, and *** represent the significance levels of 10%, 5%, and 1%, respectively; robust standard error is in parentheses.

Similarly, the IAI had a significant negative impact on the degree of standardized use by farmers at the statistical level of 5%, and the coefficient was −0.372, i.e., the total effect was −0.372. After adding the information feedback mechanism, the IAI had a significant negative influence on the degree of standardized use by farmers at the statistical level of 1%. Meanwhile, the information feedback mechanism significantly and negatively affected the degree of standardized use by farmers at the statistical level of 5%, and the coefficient was −0.069. The information-sharing mechanism had a partial mediating effect on the influence of the IAI on the standardized use of antimicrobials by farmers, and the mediating effect was −0.081 (1.170 × −0.069), accounting for 21.77% (−0.081/−0.372) of the total effect. Consequently, the IAI affected farmers' decisions and the degree of standardized use of antimicrobials through the information feedback mechanism, and thus H3 was assumed. The possible explanation was that farmers' standardized use of antimicrobials rather than overuse was often detected by testing for antimicrobial residues in the slaughtering or marketing process [63,64]. An Internet-based food traceability system could feed information on antimicrobial use back to farmers and stakeholders. Liability traceability could constrain farmers to standardize the use of antimicrobials [43].

4.3. Heterogeneity Analysis Based on the Age and Breeding Time

According to the model estimation results in Table 4, the households' age had no significant influence on farmers' decisions and the degree of standardized use of antimicrobials. However, elderly farmers had cognitive or technical barriers to Internet use, and the "digital divide" issue was more prominent in the elderly group. Therefore, the surveyed farmers were divided into under 36 years old (27 households), 36–60 years old (421 households), and over 60 years old (227 households) groups. The IV-Heckman model was adopted to explore the influence of the IAI on the standardized use of antimicrobials by farmers of different ages. The results in Table 5 showed that the IAI could significantly influence the standardized use of antimicrobials by farmers under 36 years old, motivate them to improve the decision probability of standardized use of antimicrobials, and reduce the payment amount of standardized use. However, the IAI has had little influence on the standardized use of antimicrobials by farmers over 60. Thus, if the age differences were not considered, the impact of the IAI on the standardized use of antimicrobials by farmers under 36 years of age might be overlooked. The possible explanation was with the transfer of rural young and middle-aged laborers and non-agricultural employment: elderly farmers had become the main force of agricultural production [65]. Just as Si et al. [8,60] held, due to limited educational level and experience, alleviating the "digital divide" of elderly farmers should be the government's focus in implementing the standardization of antimicrobials.

Table 5. Analysis results based on the heterogeneity of the age.

Variables	Under 36 Years Old		36–60 Years Old		Over 60 Years Old	
	Regression 16	Regression 17	Regression 18	Regression 19	Regression 20	Regression 21
	Decision	Degree	Decision	Degree	Decision	Degree
IAI	0.378 *** (0.145)	−0.579 ** (0.239)	0.374 * (0.192)	−0.276 (0.386)	0.129 (0.211)	−0.240 (0.367)
Control variables	controlled	controlled	controlled	controlled	Controlled	controlled
Sample size	27	5	421	125	227	58

Note: *, **, and *** represent the significance levels of 10%, 5%, and 1%, respectively; robust standard error is in parentheses.

In addition, to verify the nonlinear relationship between breeding time and farmers' standardized use of antimicrobials, according to the heterogeneity of breeding time, we divided the surveyed farmers into less than five years (173 households), 5–15 years

(421 households), and more than 15 years (81 households) groups. The IV-Heckman model was used to explore the impact of the IAI on the standardized use of antimicrobials by farmers with different breeding times. The results in Table 6 showed that the IAI only positively and significantly influenced the standardized use decisions of farmers whose breeding years were less than five years. However, the IAI harmed the standardized use decisions of farmers with more than 15 years of breeding time but did not pass the significance test. However, according to the results in Table 4, the breeding time negatively and significantly influenced farmers' decisions on standardized use at the significance level of 5%. This suggested that the impact of the IAI on standardized use decisions of farmers with less than five years of breeding time would be misestimated without heterogeneity analysis, which was contrary to Lekagul et al.'s [53] study. For a long time, small farmers in developing countries had been engaged in agricultural production mainly based on experience and traditional knowledge [66]. Dependence on experience also inhibited their willingness to adopt standardized techniques for using antimicrobials.

Table 6. Analysis results based on the heterogeneity of the breeding time.

Variables	Less than 5 Years		5–15 Years		More than 15 Years	
	Regression 22	Regression 23	Regression 24	Regression 25	Regression 26	Regression 27
	Decision	Degree	Decision	Degree	Decision	Degree
IAI	0.036 *** (0.004)	−0.099 (0.078)	0.049 (0.101)	−0.005 (0.016)	−0.038 (0.276)	−0.028 (0.093)
Control variables	controlled	controlled	controlled	controlled	Controlled	controlled
Sample size	173	39	421	119	81	30

Note: *** represents the significance level of 1%, respectively; Robust standard error is in parentheses.

5. Conclusions

Information or skill constraints are the main factors in standardizing the use of antimicrobials by farmers. The Internet has become the main source of farmers' information acquisition. Using data from 675 hog farmers from Hebei, Shandong, Henan, and Hubei provinces of China, the IV-Heckman model is used to analyze the influence of the IAI on farmers' standardized use of veterinary antimicrobials. The main conclusions are as follows: first, the IAI helps standardize the use of veterinary antimicrobials. Second, information-sharing and feedback mechanisms partially mediate the relationship between the IAI and farmers' standardized use of antimicrobials. Finally, based on the heterogeneity of households' age and breeding time, our study confirms that the IAI only incentivizes farmers' standardized use of antimicrobials under 36. Meanwhile, the IAI has a positive and significant influence on the standardized use decisions by farmers with less than five years of breeding time.

Of course, the study still has some flaws. Disease degree, risk preference, and expected loss may also affect farmers' standardized use of antimicrobials. Still, these variables are not included due to the limitations of data acquisition. Additionally, due to the difficulty in selecting instrumental variables, we only selected one without an over-identification test. These research deficiencies will become the focus of the research group in the future.

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