Role of risk perception and government regulation in reducing over-utilization of veterinary antibiotics: Evidence from hog farmers of China

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ARTICLE INFO

Article history:
Received 11 September 2022; Received in revised form 13 October 2022; Accepted 14 October 2022
Available online 25 October 2022

ABSTRACT

Antibiotic residues and resistance caused by farmers’ overuse of veterinary antibiotics have severely damaged global food safety, the ecological environment, and public health. How to lessen the over-utilization of antibiotics is of prime concern nowadays; however, the existing literature has paid little attention. So, to fill this gap, the current study explores the role of risk perception and government regulation in reducing the over-utilization of veterinary antibiotics by gathering data from 675 hog farmers in the Hebei, Henan, Hubei, and Shandong provinces of China. The Heckman two-stage model is employed to explore the phenomenon. Meanwhile, risk perception is categorized into food security risk perception (FSRP), ecological security risk perception (ESRP), and public health risk perception (PHRP), and government regulation is measured from antibiotic prescribed policy (APP), withdrawal period policy (WPP), and antibiotic recorded policy (ARP). The results showed that the PHRP (ODC: ME = -0.073, SE = 0.018; ODG: ME = -0.125, SE = 0.047) significantly inhibits farmers’ overuse of antibiotics. In contrast, the ESRP and PHRP have not shown significant results in influencing farmers’ overuse of antibiotics. Moreover, the APP (ODC: ME = -0.035, SE = 0.016; ODG: ME = -0.088, SE = 0.040) and WPP (ODC: ME = -0.072, SE = 0.039; ODG: ME = -0.175, SE = 0.097) significantly reduce antibiotics overuse, but the influence of the ARP on farmers’ antibiotics overuse is not apparent. Further, a moderating effect model is used to analyze the moderating effect of government regulation on farmers’ overuse of antibiotics influenced by risk perception. The results showed that the APP (ODC: ME = -0.041, SE = 0.012; ODG: ME = -0.075, SE = 0.018) and WPP (ODC: ME = -0.058, SE = 0.015; ODG: ME = -0.076, SE = 0.019) positively influence farmers’ overuse of antibiotics impacted by public health risk perception. In contrast, the ARP has no positive reinforcement effect. Finally, the study proposes that government should devolve the supervision power to veterinarians, strengthen the regulation policy advocacy, conduct training programs for farmers regarding skills to use antibiotics, and strengthen biosafety measures.

1. Introduction

Antibiotics in the veterinary sector play a crucial role in treating infectious diseases, improving livestock production efficiency, and boosting the high-quality development of animal husbandry [1,2]. More importantly, antibiotics can mitigate production and market risks driven by poor rearing environments or insufficient management techniques in some developing countries [3,4]. Farmers often overuse antibiotics instead of dosages prescribed by the instructions or recommended by veterinarians’ prescription [5–7]. Consequently, over-utilization of antibiotics severely harms the meat-derived food, soil & water, etc., the ecological environment, and public health [8–10]. Specifically, antibiotic residues directly and adversely influence the meat product’s quality and, in turn, unfavorably influences international trade and eventually lead to food supply chain obstacles at the global level [11]. Moreover, antibiotics directly discharge into water or soil through feces or sewage, which results in ecological deterioration and eventually damages human health [12–14]. Furthermore, resistant bacteria in animals directly or indirectly cause damage to public health [15]. It is generally found that infections caused by resistant bacteria are more
difficult to treat than infections caused by non-resistant bacteria [16,17], leading to the increased treatment duration and causes labour loss and heavier healthcare burden [18].

According to the report of the World Bank, it is estimated that antibiotic residues and resistance will reduce the global GDP by 1.1% to 3.8% [19,20]. Therefore, how to reduce the overuse of antibiotics by farmers has become a major and urgent issue to be solved. In this regard, government regulation is considered the most important external force that may restrict the farmers’ over-utilization of antibiotics. However, the existing literature reflects that information asymmetry is the main factor leading to over-utilization. Moreover, both the government and consumers can not accurately monitor and predict farmers’ antibiotic use, so it becomes challenging to regulate farmers’ behaviour [21,22].

Further, the farmer’s behaviour is also influenced by several other practices [23]. So, the core factor in addressing the overuse of veterinary antibiotics is strengthening the cooperation between farmers and other actors, such as the government [24]. The interaction between farmers and the government can lead to the exchange of symmetrical information, especially about the dose of antibiotics used [25,26]. The government can play a substantial role by not only stating the unsafe production behaviour from coercive means such as antibiotic prescribed, withdrawal period, and antibiotic recorded policies and thus force farmers to regulate the use of veterinary antibiotics, but also from the non-coercive means, such as subsidizing the cost of antibiotics to change the farmers’ external environment and stimulate their behaviour and motivation towards regulating antibiotics use [27–29]. However, information asymmetry may increase the gap between the goals and implementation outcomes of coercive and non-coercive government instruments [30]. In the existing literature, many earlier researchers affirmed that government regulations such as supervision and penalty and economic incentive policies such as subsidies are insignificant in reducing the farmers’ antibiotic overuse [31–33]. Furthermore, if farmers continue using antibiotics excessively, government supervision and penalty can create an illegal market [34,35]. Consequently, addressing the information asymmetry in farmers’ overuse of antibiotics is crucial.

According to the theory of agricultural economics, farmers combine their endowments with external constraints to make decisions to achieve their maximum benefit [36,37]. Therefore, in addition to the role of government regulation, individual factors are also likely to address the information asymmetry issue. Some scholars argue that weak risk perception contributes to farmers’ overuse of antibiotics [38–41]. Risk perception refers to the farmers’ subjective assessment of risk probability based on their experience and plays an essential role in farmers’ decision-making behaviour towards risk [39]. The stronger the risk perception, the more inclined farmers are to opt for risk-resistance behaviours. Studies have confirmed that risk perception encourages farmers to disclose production information, such as participating in the traceability system by ensuring product quality, maintaining production reputation, reducing expected losses, and enhancing social responsibility [42–45]. Besides, it also strengthens the cooperation between farmers and the government in extending the industrial chain and ultimately alleviates the issue of information asymmetry [46,47].

Nevertheless, suppose farmers are fully aware of the related risks associated with the overuse of antibiotics. In that case, there is a wide discrepancy concerning whether they will make behavioural changes to reduce the potential risks and resist the overuse of antibiotics in the production process. Some scholars believe that once farmers realize the risk of overuse of antibiotics, the risk of damage, such as bacterial resistance and human infectious diseases, leads them to reduce antibiotic overuse [41,48,49]. However, other scholars believe that almost all farmers know about food safety and environmental safety risks associated with their behaviour. Still, the realization and consequences of risks are externalized or borne by the public, so they continue to utilize antibiotics excessively [50–53]. The fundamental reason for the above controversy is that the existing literature has paid no attention to the heterogeneity of risk perception. Food and ecological security risks have obvious externalities; farmers usually transfer these risks at a lower cost. However, public health risk directly threatens the health of farmers themselves, and they may reduce the overuse of antibiotics.

Apart from government regulation and risk perception, other factors may influence farmers overusing antibiotics. Some scholars believe that the low cost of antibiotic use and the lack of elasticity of demand [54], overly sensitive or overestimated disease losses [52], trust bias in the effectiveness of veterinary antibiotics [55], and high reliance on antibiotics [56] are the main reasons for farmers’ overuse of antibiotics. Besides, other studies revealed that individual characteristics such as gender, age, and education level [55,57], family characteristics such as farmland area, family labourers, and non-farm employment [58,59], production characteristics such as breeding time, breeding purpose, breeding experience, organizational participation, information acquisition, biological measures, sales channels [11,32,60], social aspects such as relationship network, social learning, group supervision, and peer effects [5,34,51] are also some other factors affecting the overuse of antibiotics. Identifying the above influencing factors also provides an essential reference for analyzing the overuse of antibiotics by farmers.

In China, hog breeding is regarded as a traditional pillar industry. It extensively encompasses the agricultural economic structure and contributes to poverty alleviation and rural revitalization in marginalized and deprived areas [12,61]. According to the announcement of the National Bureau of Statistics of China, pork consumption accounts for 49.1% of global consumption, and the number of pigs bred accounts for 56.6% of the global pigs reared [62]. Meanwhile, China is the world’s largest producer and consumer of antibiotics; >160,000 tons of antibiotics are produced annually, of which 52% are veterinary antibiotics [26]. The issue of the overuse of antibiotics by farmers is a grim situation, and China has already adhered to bring a reduction in the utilization of antibiotics. Moreover, to avoid information asymmetry between the government and farmers, the Chinese government opted for several policy measures such as prescribed antibiotics, withdrawal period, and recorded antibiotics. So, now the question arises, can these government regulatory measures effectively alleviate and reduce the information asymmetry and overutilization of antibiotics by farmers? Does any internal interaction between government regulation and farmers’ risk perception affect the farmers’ behaviour? To answer these questions, the current study firstly analyses certain aspects of risk perception or government regulation. The risk perception is categorized into the FSRP, ESRP, and PHRP, while government regulation is measured using APP, ARP, and WPP. Moreover, risk perception and government regulation are incorporated into a unified analytical framework. The Heckman two-stage model explores the influence of risk perception and government regulation on farmers’ antibiotics overuse. The study used data gathered from 675 hog farmers from Hebei, Henan, Hubei, and Shandong provinces of China. Furthermore, to explore the interactive relationship between risk perception and government regulation, the moderating effect model is adopted to analyze the moderating effect of government regulation on farmers’ overuse of antibiotics influenced by risk perception. In last, the study provides the policy implications to reduce the antibiotic use at the global level.

2. Materials and methods

2.1. Study sites, sampling, and participants

The data was gathered from the field survey of 16 counties of China, i.e., Hebei, Shandong, Henan, and Hubei provinces, from July to September 2021 (Fig. 1). Before the formal investigation, the research team conducted a pre-investigation on Jiyuan, Henan Province, and revised the relevant contents of the questionnaire. These provinces were chosen given the fact these were the main production areas of hogs in China. In 2020, the number of hogs raised in Hebei, Shandong, Henan, and Hubei was 17.488, 29.339, and 38.879, and 21.615 million,
respectively. The density and scale of hogs bred were relatively large. Meanwhile, apart from large-scale enterprises, the standardization degree of small-scale breeding was highly weak, the incidence of epidemic diseases was very high, and the use of veterinary antibiotics was relatively large. The survey reported that the incidence of infectious diarrhoea in piglets was about 27.15%, 30.20%, 26.15%, and 27.38% in Hebei, Shandong, Henan, and Hubei provinces, respectively.

The research team conducted the questionnaire survey in two ways: the survey team conducted face-to-face interviews with the farmers and then conducted the questionnaire survey with the interviewed farmers. Meanwhile, the research group also sought the help of local livestock departments in completing questionnaires from farmers who were inconvenient to contact. The method of combining stratified sampling and random sampling was adopted in the questionnaire survey. 2–4 sampled towns were randomly selected in each county, and 12–16 farmers engaging in rearing hogs were randomly chosen in each town for questionnaire surveys. A total of 750 questionnaires were distributed in the study, excluding information omissions or suspected fake samples, and finally, 675 valid questionnaires were obtained with a questionnaire efficiency of 90%. The Kaiser-Meyer-Olkin (KMO) value of the questionnaire was 0.812, indicating that the questionnaire had good reliability and representativeness.

2.2. Variable selection

2.2.1. Dependent variables

The dependent variable in this paper is farmers’ overuse of antibiotics. Previous literature mainly characterized farmers’ behaviour from behaviour decisions and behaviour degree [42,63,64]. Therefore, we described farmers’ overuse of antibiotics as overuse-decision and overuse-degree. Specifically, if a farmer decided to overuse antibiotics, the value of 1 was assigned; otherwise, the value was 0. The main veterinary antibiotics used by farmers in the sample area include Tetracyclines, Sulfonamides, and β-lactams. For the overuse degree, the prescribed doses of the instructions (non-prescription antibiotics) and the recommended doses prescribed by veterinarians (prescription antibiotics) were used as a standard for the standardized use of antibiotics. According to the information recorded or expenditure amount of antibiotics, if a farmer’s actual dose was more than the standard dose, they were known as the overuse group. Therefore, overuse-degree is the difference between basic and standard doses. Furthermore, due to the strong heterogeneity in the packaging type, such as bottled and bagged antibiotics and measurement units such as grams, millilitres, and tablets, the overdose of antibiotics was transformed into expenditures; that is, the money was needed to purchase antibiotics used by farmers. Thus, the continuous variable is employed to reflect usage degree.

2.2.2. Independent variables

The explanatory variables are risk perception and government regulation. The risk perception is categorized into FSRP, ESRP, and PHRP based on the risk damage caused by the overuse of antibiotics. The questionnaire encompasses the questions such as “did you think overuse of antibiotics can harm food security, ecological security, and public health? The answers were measured on the Likert five-point scale ranging from completely impossible = 1 to completely possible = 5. Besides, since China’s livestock department mainly adopted imperative regulatory policies to restrain farmers from overusing antibiotics, this paper deliberated government regulation from the APP, ARP, and WPP perspectives, which were measured by whether these policies were compiled by farmers. If a farmer followed this policy, a value of 1 was assigned; otherwise, the value is 0. Therefore, these policies are discrete binary variables. The APP refers to the purchase and use of antibiotics based on a prescription from a licensed veterinarian. The ARP lets farmers keep detailed records of the type of infectious disease and the
time, quantity, and frequency of antibiotic use. The WPP refers to the time interval for stopping and dropping using antibiotics in livestock to the below-safe standards. Different antibiotics had different withdrawal periods, generally 1–28 days.

2.2.3. Control variables

Referring to related studies by Ji et al. [65] and van Asseldonk et al. [66], the head of the household’s gender, age, education level, breeding year, degree of specialization, organizational participation, transaction model, peer effect, and relationship network are used as control variables in the current study. According to the statistical analysis (Table 1), the majority (72.10%) of the farmers is inclined towards using antibiotics excessively, and the average overdose is found at 379.334 yuan/household. The risk perception level of farmers is found low, and the mean values of FSRP, ESRP, and PHRP are 2.791, 2.539, and 2.669, respectively. Moreover, the intensity of government regulation is also found weak, and only 37.90%, 48.10%, and 62.30% of farmers followed APP, ARP, and WPP, respectively. Moreover, 73.40% of households are headed by a male, and a female’s influence in family decision-making is relatively weak. The average age in the current study is found at around 56 years old, and the education level of 6 years, indicating that the quality of the rural labors is low. Additionally, the actual time of farmers engaged in breeding hog is about 9 years and the degree of specialization is close to 70%, showing that the hog industry is the main source of family income in the sampled area. Moreover, it is also found that only 41.40% of farmers joined the cooperative organizations, and the proportion of fixed order transactions is only 33.30%. Besides, the mean values of peer effect and relationship network are 3.448 and 0.285, respectively. The actual distance from the hog house to the veterinary workstation (km) is 6.207 km, indicating that it is difficult for farmers to obtain veterinary services.

2.3. Research method

Following the studies of Sarma [67] and Abbasi and Kim [68], this paper employed the Heckman two-stage method to explore the influence of risk perception and government regulation on farmers’ overuse of antibiotics. The main reasons for model selection are as follows: the dependent variable in the paper includes two stages of overuse-decision and overuse-degree. If farmers do not choose to overuse antibiotics (first stage), their overdose and the degree are not directly observed (second stage), so there is a sample selection issue for farmers’ antibiotic overuse. Meanwhile, the explanatory factors in the outcome equation (second stage) should be a complete subset of the explanatory factors in the selection equation (first stage) [69]. Additionally, at least one explanatory variable in the selection equation has not appeared in the outcome equation. Therefore, “distance between hog house and veterinary workstation” is selected as the identifying variable, and the Heckman two-stage method is constructed as follows:

\[ y_0 = X_i' \alpha + \mu_i \]
\[ y_1 = \begin{cases} y_{1i} > 0 & \text{if } y_{1i} > 0 \\ \theta y_{1i} > 0 & \text{if } y_{1i} \leq 0 \end{cases} \]  

\[ y_2 = X_i' \beta + \mu_i \]
\[ y_\gamma = \begin{cases} y_{\gamma i} > 0 & \text{if } y_{\gamma i} > 0 \\ 0 & \text{if } y_{\gamma i} \leq 0 \end{cases} \]

Where Eq. (1) represents the selection equation in the first stage, and Eq. (2) is the result equation in the second stage. The subscript \(i\) indicates the \(i\)-th sample farmer and \(y_{1i}\) signifies the farmer’s overuse-decision, and \(y_{\gamma i}\) indicates the farmer’s overuse-degree. \(X_1\) and \(X_2\) represents the explanatory variables of the two equations, respectively. The subscript \(y_{\gamma i}\) refers to the unobservable latent variable, and \(b\) signifies the overuse-degree. If \(y_{\gamma i} > 0, y_{\gamma i} \) could be observed. \(\alpha\) and \(\beta\) are the parameters to be estimated; \(\mu_i\) and \(\mu_\gamma\) represents the residuals, all of which follows the normal distribution. The conditional expectation for the farmer’s overuse-degree is expressed as follows:

\[ E(y_{\gamma i}|y_{1i} = c) = E(y_{\gamma i}|y_{1i} > 0) = E(X_i' \beta + \mu_j|X_i' \alpha + \mu_i > 0) = E(X_i' \beta + \mu_j|X_i' \alpha > -X_i' \alpha) = X_i' \beta + \rho \sigma \mu_\gamma \lambda(-X_i' \alpha) \]

Table 1

| Variables | Assignment of variables | Max | Min | Mean | S.E. |
|-----------|-------------------------|-----|-----|------|------|
| Overuse-decision | Yes = 1, No = 0 | 1 | 0 | 0.721 | 0.448 |
| Overuse-degree | The actual amount of antibiotics used minus the amount of antibiotics prescribed (yuan) | 1722.975 | 379.344 | 139.753 |
| FSRP | Did overused antibiotics increase the risk of antibiotic residues in food? (Completely impossible –1—Completely possible –5) | 5 | 1 | 2.791 | 1.320 |
| ESRP | Did overused antibiotics increase the risk of antibiotic residues in soil and water? (Completely impossible –1—Completely possible –5) | 5 | 1 | 2.539 | 1.198 |
| PHRP | Did overused antibiotics increase the risk of bacterial resistance? (Completely impossible –1—Completely possible –5) | 5 | 1 | 2.669 | 1.240 |
| APP | Did you obtain antibiotics according to veterinary prescription? (Yes = 1, No = 0) | 1 | 0 | 0.379 | 0.485 |
| ARP | Did you record antibiotic use information? (Yes = 1, No = 0) | 1 | 0 | 0.481 | 0.500 |
| WPP | Did you strictly enforce the antibiotic withdrawal period? (Yes = 1, No = 0) | 1 | 0 | 0.623 | 0.484 |
| Gender | Male = 1, female = 0 | 1 | 0 | 0.734 | 0.441 |
| Age | Actual age (years) | 87 | 24 | 55.884 | 10.986 |
| Education level | The actual time of education (years) | 16 | 0 | 5.951 | 3.761 |
| Breeding year | The actual time of engaged in breeding hog (year) | 37 | 0 | 8.577 | 5.164 |
| Degree of specialization | The ratio of income of rearing hog to total family income (0-1) | 0.960 | 0.113 | 0.690 | 0.214 |
| Organizational participation | Did you join a cooperative? (Yes = 1, No = 0) | 1 | 0 | 0.414 | 0.493 |
| Transaction model | Fixed order transaction = 1, free market transaction = 0 | 1 | 0 | 0.333 | 0.471 |
| Peer effect | Did other farmers’ behaviour influence your antibiotic use? (Completely impossible –1—Completely possible –5) | 5 | 1 | 3.448 | 1.279 |
| Relationship network | Did you have a veterinarian among your relatives or friends? (Yes = 1, No = 0) | 1 | 0 | 0.285 | 0.452 |
| Distance between hog house and veterinary workstation | The actual distance from the hog house to the veterinary workstation (km) | 15 | 1 | 6.207 | 4.324 |

Note: 1-yuan RMB = 0.1446 USD.
3. Results

3.1. Statistical inference

To identify the relationship between the dependent and the independent variables, the overuse decision is primarily divided into two groups: the overuse group and the non-overuse group. Meanwhile, the mean of the overuse-degree is taken as the centre point, the overuse-degree is split into high and low groups, and the independent sample t-test is used to analyze the differences between risk perception and government regulation (Table 2). In the context of overuse decisions, the PHRP, APP, and WPP are significantly different at a 1% level between decision and overuse-degree of antibiotics. While the FSRP, ESPR, and 0.097) all had a significant inhibitory effect on farmers and WPP (ODC: ME = 0.138, and 0.186, respectively, indicating that the PHRP, APP, and WPP might negatively correlate with farmers’ overuse of antibiotics.

3.2. Influence of risk perception and government regulation on farmers’ antibiotic overuse

According to the Heckman’s two-stage model that is used to empirically analyze the impact of risk perception and government regulation on farmers’ overuse of antibiotics (Model 1), the results showed that the Wald chi-square and LR values are significant at 1% and 5% levels, respectively, indicating that the overall model fitting effect is good. Meanwhile, the inverse mills rate (probability of potential farmers overuse and overuse-degree of antibiotics) has a significant positive impact on the overuse-degree of antibiotics by farmers, showing that some omitted variables are possible factors that affect both farmers’ overuse-decision and overuse-degree. Hence, there is a sample selection issue. Additionally, the distance between the hog house and the veterinary workstation also showed a positive and significant impact on farmers’ overuse-decision of antibiotics at a 1% significance level, revealing that the identification variable in the model is appropriate.

Table 2
The results of the independent sample t-test.

| Variables | Overuse-decision | Overuse-degree | Difference | Difference |
|-----------|------------------|----------------|------------|------------|
|           | Overuse group   | Non-overuse    | High group | Low group  | A-B   | C-D   |
|           | (A)             | (B)            | (C)        | (D)        |       |       |
| FSRP      | 3.001           | 2.581          | 2.905      | 2.677      | 0.420 | 0.228 |
| ESPR      | 2.619           | 2.459          | 2.790      | 2.288      | 0.160 | 0.502 |
| PHRP      | 2.867           | 2.471          | 2.917      | 2.421      | 0.396*** | 0.496** |
| APP       | 0.491           | 0.267          | 0.448      | 0.310      | 0.224*** | 0.138** |
| ARP       | 0.504           | 0.458          | 0.485      | 0.477      | 0.046 | 0.008 |
| WPP       | 0.729           | 0.517          | 0.716      | 0.530      | 0.212*** | 0.186** |

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

3.3. Robustness test for benchmark regression model

To examine the robustness of the benchmark regression model, this paper further relaxed the conditional constraints of the Heckman two-stage model, which is likely to overcome the sample selection bias and require simultaneous estimation of decision-equation and outcome-equation. The study used the Probit and Tobit models to explore the influence of risk perception and government regulation on farmers’ antibiotic overuse. The Probit model is suitable for model estimation where the dependent variable is a discrete binary variable such as farmers’ overuse-decision; the Tobit model is applied for tail-cut data, such as farmers’ overuse-degree. The robustness estimation results (Table 3) show that, comparatively, benchmark regression results (model 1), model 2, and 3’s marginal effect value increases slightly, indicating that the Heckman two-stage model’s estimation results have good robustness. Moreover, if the sample selection issue is not considered, the effects of risk perception and government regulation will be overestimated. (See Table 4)

3.4. Moderating effect of government regulation on risk perception affecting farmers’ overuse of antibiotics

To verify the moderating effect of government regulation on risk perception affecting farmers’ antibiotic overuse, the study further used grouped regression and Heckman’s two-stage model to analyze the estimated results of the moderating effect model. In the sample, 256, 325, and 421 farmers complied with the APP, ARP, and WPP, respectively. Moreover, Tables 5-7 portray the moderating effect of the APP, ARP, and WPP on risk perception influencing the overuse of antibiotics by farmers. According to Tables 5 and 7, the APP (ODC: ME = -0.041, SE = 0.012; ODG: ME = -0.075, SE = 0.018) and WPP (ODG: ME = -0.058, SE = 0.015; ODG: ME = -0.076, SE = 0.019) has significant and negative regulatory effect on the PHRP influencing farmers’ overuse of antibiotics. Specifically, if farmers complied with the APP, the probability of overuse and overuse-degree of antibiotics influenced by the PHRP will decrease by 4.10% and 7.5 yuan; if farmers complied with the WPP, the probability of overuse and overuse-degree of antibiotics impacted by the PHRP would decrease by 5.8% and 7.6 yuan. In contrast, the ARP is not showing a regulatory effect.
Table 3
Estimation results of the Heckman two-stage model.

| Variables | Model 1 |  |  |
|-----------|---------|---------------|------------|
|           | First stage | Second stage |  |
|           | (Overuse-decision, ODC) | (Overuse-degree, ODG) |  |
| FSRP      | -0.057 | -0.074 |  |
|           | (0.038) | (0.055) |  |
| ESRP      | -0.047 | -0.066 |  |
|           | (0.038) | (0.045) |  |
| PHRP      | -0.073*** | -0.125*** |  |
|           | (0.018) | (0.047) |  |
| APP       | -0.035** | -0.088** |  |
|           | (0.016) | (0.040) |  |
| ARP       | 0.029 | 0.063 |  |
|           | (0.035) | (0.047) |  |
| WPP       | -0.072* | -0.175* |  |
|           | (0.039) | (0.097) |  |
| Gender    | -0.063*** | -0.043*** |  |
|           | (0.030) | (0.012) |  |
| Age       | 0.000 | 0.000 |  |
|           | (0.000) | (0.001) |  |
| Education level | -0.001 | -0.013 |  |
|           | (0.002) | (0.008) |  |
| Breeding year | -0.000 | -0.002 |  |
|           | (0.001) | (0.002) |  |
| Degree of specialization | -0.025*** | -0.083*** |  |
|           | (0.006) | (0.023) |  |
| Organizational participation | -0.019 | -0.067** |  |
|           | (0.020) | (0.027) |  |
| Transaction model | -0.039 | -0.049* |  |
|           | (0.032) | (0.025) |  |
| Peer effect | -0.007 | 0.003 |  |
|           | (0.008) | (0.010) |  |
| Relationship network | -0.040* | 0.061 |  |
|           | (0.022) | (0.051) |  |
| Distance between farm and veterinary station | 0.025*** | - |  |
|           | (0.004) | - |  |
| Inverse Mills ratio (IMR) | - | 0.230*** |  |
|           | - | (0.062) |  |
| Wald Chi-square value | 5.262*** | 3.532*** |  |
|           | (0.876) | (1.39) |  |
| Log-likelihood Ratio value | 169.38*** | -141.499** |  |

Note: *, **, and *** represented significance at the 10%, 5%, and 1% levels, respectively. Values outside the parentheses represented the marginal effect values. Values in parentheses represented the standard error of robustness.

Table 4
The results of the robustness test.

| Variables | Probit-model 2 | Tobit-model 3 |
|-----------|---------------|---------------|
|           | Overuse-decision | Overuse-degree |  |
| FSRP      | -0.061 | -0.077 |  |
|           | (0.039) | (0.058) |  |
| ESRP      | -0.049 | -0.072 |  |
|           | (0.038) | (0.048) |  |
| PHRP      | -0.078*** | -0.131*** |  |
|           | (0.021) | (0.036) |  |
| APP       | -0.043** | -0.091** |  |
|           | (0.019) | (0.043) |  |
| ARP       | 0.031 | 0.067 |  |
|           | (0.025) | (0.048) |  |
| WPP       | -0.075* | -0.181* |  |
|           | (0.039) | (0.096) |  |
| _Cons     | 4.032*** | 2.062*** |  |
|           | (0.675) | (0.079) |  |
| Control variables | Controlled | Controlled |  |

Note: *, **, and *** represented significance at the 10%, 5%, and 1% levels, respectively. Values outside the parentheses represented the marginal effect values. Values in parentheses represented the standard error of robustness.

Table 5
Moderating effect of the APP.

| Variables | Model 4 |  |  |
|-----------|---------|---------------|------------|
|           | First stage | Second stage |  |
|           | (Overuse-decision, ODC) | (Overuse-degree, ODG) |  |
| FSRP      | -0.031 | -0.036 |  |
|           | (0.020) | (0.025) |  |
| ESRP      | -0.021 | -0.043 |  |
|           | (0.032) | (0.035) |  |
| PHRP      | -0.041*** | -0.075*** |  |
|           | (0.012) | (0.019) |  |
| Distance between hog house and veterinary workstation | 0.012*** | -0.014*** |  |
|           | (0.004) | (0.005) |  |
| Control variables | Controlled | Controlled |  |
| Sample size | 256 | 419 |  |

Note: *, **, and *** represented significance at the 10%, 5%, and 1% levels, respectively. Values outside the parentheses represented the marginal effect values. Values in parentheses represented the standard error of robustness.

Table 6
Moderating effect of the ARP.

| Variables | Model 4 |  |  |
|-----------|---------|---------------|------------|
|           | First stage | Second stage |  |
|           | (Overuse-decision, ODC) | (Overuse-degree, ODG) |  |
| FSRP      | -0.037 | -0.015 |  |
|           | (0.025) | (0.026) |  |
| ESRP      | -0.022 | -0.036 |  |
|           | (0.031) | (0.031) |  |
| PHRP      | -0.052 | -0.071 |  |
|           | (0.039) | (0.048) |  |
| Distance between hog house and veterinary workstation | 0.017*** | -0.015*** |  |
|           | (0.005) | (0.004) |  |
| Control variables | Controlled | Controlled |  |
| Sample size | 325 | 350 |  |

Note: *, **, and *** represented significance at the 10%, 5%, and 1% levels, respectively. Values outside the parentheses represented the marginal effect values. Values in parentheses represented the standard error of robustness.

Table 7
Moderating effect of the WPP.

| Variables | Model 4 |  |  |
|-----------|---------|---------------|------------|
|           | First stage | Second stage |  |
|           | (Overuse-decision, ODC) | (Overuse-degree, ODG) |  |
| FSRP      | -0.049 | -0.078 |  |
|           | (0.052) | (0.056) |  |
| ESRP      | -0.061 | -0.049 |  |
|           | (0.052) | (0.055) |  |
| PHRP      | -0.058*** | -0.076*** |  |
|           | (0.015) | (0.019) |  |
| Distance between hog house and veterinary workstation | 0.016*** | -0.015*** |  |
|           | (0.004) | (0.004) |  |
| Control variables | Controlled | Controlled |  |
| Sample size | 421 | 254 |  |

Note: *, **, and *** represented significance at the 10%, 5%, and 1% levels, respectively. Values outside the parentheses represented the marginal effect values. Values in parentheses represented the standard error of robustness.
4. Discussion

4.1. The relationship between information asymmetry and the dilemma of antibiotic governance

Like human antibiotics, veterinary antibiotics are essential for treating bacterial infections, maintaining animal health and welfare, and improving livestock productivity [70,71]. The world generally believes that the most fundamental strategy for reducing risks of meat-derived food safety, ecological security, and public health caused by antibiotic residues and resistance is to strengthen biosecurity measures and mitigate infectious diseases [58,59,72]. However, it is difficult for most developing countries that depend on animal husbandry. Many scholars hold that with strained veterinary resources, limited access to diagnosis, and few controls on antibiotic use in animals, the need to address antibiotic residues and resistance is more urgent in developing countries than in developed countries [73–75]. According to the agricultural economics theory, farmers’ overuse of antibiotics eliminates the risk of disease and production, improves production efficiency, and increases family income. Hence, the compatibility of reducing antibiotics overuse, residues, and resistance with eliminating the risk of disease and rising production pose serious challenges to public governance [54,60].

Moreover, the information asymmetry during farmers’ antibiotic use is another dilemma of antibiotic governance [76,77]. Antibiotic efficacy is a common pond resource, and farmers often do not consider the residual and resistance costs [57,78]. Farmers also formally use their information advantages to enjoy policy dividends in the game with the government, such as obtaining subsidies but not reducing the overuse of antibiotics [79,80]. Hence, reducing information asymmetry has become the focus of academic studies. Our study mainly discusses the formation mechanism of farmers’ antibiotics overuse from internal factors such as risk perception and external factors such as government regulation. Risk perception is a concept used to describe a farmer’s intuitive judgment of a certain type of risk event and contains both loss and gain uncertainty [81,82]. Risk perception is essential for actors to actively disclose information, accept social supervision, and form self-governance [83]. Meanwhile, government regulation also drives actors to increase information supply through behavioural constraints, policy incentives, or technical guidance [84,85]. The main innovation of this paper is to describe farmers’ risk perception from the FSRP, ESRP, and PHRP, and characterize government regulation from the APP, ARP, and WPP. The study further answers whether risk perception and government regulation can mitigate and reduce information asymmetry and farmers’ antibiotic overuse. The studies’ perspective and results can further enrich related theoretical connotations of public management and agricultural economics.

4.2. Discussion of empirical results

Contradictory to the findings of Dankar et al. [86] and Wemette et al. [87], the study verifies that only the PHRP acts as an inhibitor to reduce antibiotic overuse by farmers. At the same time, the FSRP and ESRP don’t play a significant role in restraining farmers’ overuse of antibiotics. Thus, our study confirms the heterogeneity of risk perception. Especially firstly, the heterogeneity of risk determines the difference in risk perception [88,89]. Risk has the attributes of public or private goods, which determines the effect of an individual’s risk perception [90,91]. Moreover, the food and ecological security risks caused by farmers’ overuse of antibiotics have typical externalities and public goods attributes. Further, hog farmers usually do not bear these risks by their information advantages but avoid or transfer adverse risks to the public through adjusting consumption behaviour or ignoring environmental pollution. Secondly, farmers are directly exposed to antibiotic-resistant bacteria, and the health damage caused by bacterial resistance now threatens them [92,93]. Consistent with Sookhtanlou et al. [94] and Anthonj et al. [95]’s studies, the PHRP drives farmers to engage in safe production behaviours through possible medical expenses, loss of health welfare, and loss of lost work income. Thus, the PHRP is an internal force driving farmers to reduce antibiotic overuse proactively. Finally, if the heterogeneity of risk perception is not considered, the effects of risk perception may be overestimated or masked.

Further, government regulation is also essential in alleviating information asymmetry, external diseconomy, and market failure [96,97]. This paper first discusses the causal relationship between the APP before antibiotic use, the ARP during antibiotic use, and the WPP after antibiotic use and farmers’ antibiotic overuse. Consistent with Alradini et al. [98], McClelland et al. [99], and Manna et al. [100]’s studies, our results confirm a significant inhibitory effect of the APP and WPP on the overuse of antibiotics by farmers. Especially and firstly, prescription antibiotics account for 95% of veterinary antimicrobials in China and can only be purchased by farmers with access to veterinarians. In recent years, China’s agricultural sector has taken rural veterinarians’ supply and service improvement as an essential starting point for revitalizing rural talents. The veterinary prescription restricts farmers from standardizing antibiotics through disease diagnosis technology, standardized medication skills, and purchase qualifications, thereby reducing farmers’ overuse of antibiotics from the root [101,102]. Secondly, some countries use the WPP as a compulsory bottom line for controlling antibiotic residues [103]. Farmers using veterinary antibiotics must observe a minimum withdrawal before slaughtering and selling animals or animal products. In recent years, China has continued to increase the construction of food traceability systems. It is possible to timely and accurately searches a farmer for meat-derived food with excessive antibiotic residues. Accordingly, information feedback, accountability, and market reputation also drive farmers to reduce antibiotic overuse [104,105]. While inconsistent with Kim et al. [6] and Holmstr et al. [10]’s studies, the ARP has no significant negative effect on farmers’ overuse of antibiotics. Recording the types of diseases and relevant information such as the dosage, frequency, time, and impact of antibiotic use is the core measure to alleviate information asymmetry, which has also become a necessary basis for the government to supervise and inspect the use of antibiotics by farmers [20,106]. If farmers fail to comply with the antibiotic recorded policy, they face uncertain risks of regulatory penalties and even loss of business qualifications. However, recording antibiotic use requires household labor and time, and so hog farmers often record poorly.

Our study also confirms the role of other control variables in reducing antibiotic overuse by farmers. Contrary to Jia and Lu [107], it is confirmed that the dominant role in family economic decision-making is of the male member. Due to the limitations of traditional habits, social psychology, role division, and social status [108], although rural women are directly involved in breeding hogs in developing countries, they do not have household decision-making power for family management and the decision to invest in antibiotics is mainly made by the male. The higher the degree of specialization, the main source of family income is from hog rearing income. Just as Wang et al. [109] and Klasen et al. [110] believe that the degree of specialization is the basis for standardized breeding of hogs, and farmers can strengthen the infrastructure, biosecurity measures, large-scale breeding, reduce the rate of infectious diseases, and ultimately reduce the use of antibiotics. Consistent with Skaalsveen et al. [111] and Gao et al. [112]’s study, our study confirms the facilitative role of relationship networks in family decision-making. Suppose a farmer has a veterinarian among relatives or friends. In that case, the cost of access to veterinary services is lower, and the more skilled the use of antibiotics, the more inclined they are to decide to reduce antibiotics use. Besides, organized participation is beneficial to reducing farmers’ information search costs and product market premiums and ultimately strengthens farmers’ safe production through technical training, service supply, and unified management [113,114]. Farmers’ decision-making power is transferred to cooperative organizations, a common operation mode of cooperatives in some
developing countries [115]. Meanwhile, farmers and cooperatives sign a fixed-order transaction contract, and the cooperative is responsible for controlling product quality and purchasing farmers’ agricultural products [116,117]. Consequently, organization participation and fixed order transaction are combined to encourage farmers to reduce the overuse of antibiotics by improving farmers’ antibiotic use technology, strengthening antibiotic use management, and detecting antibiotic residues in pork products.

4.3. Feasible countermeasures designed

This study provides some valuable insights for policymakers based on the study findings. Firstly, the government should gradually devote the supervision power to veterinarians to enhance the professionalism and normalization of policy supervision and alleviate the insufficient personnel in rural livestock departments. Meanwhile, the government should establish a digital supervision platform such as online prescriptions, electronic antibiotics records, and online withdrawal period tracking. Secondly, the government should widely publicize the implementation standards and expected effects of the APP, ARP, and WPP, especially the importance of reducing the overuse of antibiotics, maintaining food security, ecological security, and public health, and finally, improve farmers’ awareness of standardized antibiotics use. Thirdly, the government should entrust cooperative organizations to regularly train farmers regarding antibiotic use skills, such as disease diagnosis and treatment, medication technology, and drug withdrawal skills, and continuously improve the scientific and standardized level of farmers’ antibiotic use. Finally, the government should expand the scope of compulsory vaccine immunization and provide subsidies for biosafety measures such as disinfectants to reduce the incidence of livestock diseases.

4.4. Limitations of the study

Of course, the study has certain shortcomings. Firstly, veterinary antibiotics can be divided into prescription and non-prescription antibiotics and broad-spectrum and non-broad-spectrum antibiotics. The effects of risk perception and government regulation on different antibiotic types have not been analyzed. Secondly, the overuse of antibiotics by farmers has a sample selection bias, which may lead to endogeneity issues. Due to the difficulty of instrumental variable selection, we have not dealt with possible endogeneity issues in the Heckman two-stage model. Finally, the APP, ARP, and WPP, mainly adopted in China, are all imperative regulatory policies. Farmers’ overuse of antibiotics is studied from agricultural economics, while it does not consider the effects of market measures such as subsidy policies. Of course, these issues provide the focus and direction for future in-depth research.

5. Conclusion

The World Health Organization has called antibiotic residues and resistance a global crisis. Information asymmetry is the bottleneck factor for the government to intervene in farmers’ overuse of antibiotics. How to alleviate the information asymmetry and reduce farmers’ overuse of antibiotics has become an essential issue to be solved urgently in academia. This paper uses data from 675 hog farmers in the Hebei, Henan, Hubei, and Shandong provinces of China, for providing with the same breeding model, standardized rearing degree, and level of biosafety measures as China. The PHRP exerts a significant inhibitory effect on farmers’ overuse of antibiotics, and if the PHRP is increased by 1 unit, the probability of overuse and overuse-degree of antibiotics by farmers will decrease by 3.5% and 8.8 yuan, respectively; if farmers follow the WPP, the likelihood of overuse and overuse-degree of antibiotics by farmers will reduce by 7.2% and 17.5 yuan, respectively. Moreover, other control variables such as gender, degree of specialization, relationship network, organizational participation, and transaction model are found as essential drivers for farmers to reduce the overuse of antibiotics. Besides, the APP and WPP also showed a positive regulatory effect on farmers’ overuse of antibiotics influenced by the PHRP. Thus, our study confirms the substantial heterogeneity of risk perception and government regulation influencing farmers’ antibiotic overuse. Besides, these policy recommendations are more valuable for other developing countries with the same breeding model, standardized rearing degree, and level of biosafety measures as China.

Ethics statement

Not applicable.

Availability of data and materials

The datasets generated and analyzed during the modern study are not publicly available but from the corresponding author at reasonable request.

Funding

This work was supported by the National Natural Science Foundation of China (Grant No. 72103161), Shaanxi Provincial Social Science Foundation Project (Grant No. 2021D008), and Special scientific research project of Education Department of Shaanxi Provincial Government (Grant No. 21JK0205).

Authors’ contribution

Conceptualization, Data curation, Formal analysis, and Writing—original draft = Ruishi Si and Qian Lu. Methodology, Software, Supervision, and Validation = Yumeng Yao and Xin Liu. Funding acquisition and Writing—review = Mingyue Liu.

Consent for publication

Not applicable.

Declaration of Competing Interest

The authors declare that they have no competing interests.

Data availability

The data that has been used is confidential.

Acknowledgments

The authors are also thankful to the livestock department of Hebei, Henan, Shandong, and Hubei provinces of China, for providing with related data.

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