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How policy advocacy promotes regulated antibiotic use: Evidence from meat duck farmers of China

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ABSTRACT

Antibiotic residues resulting from the misuse of veterinary antibiotics pose a serious threat to global food safety and the ecological environment. Regulating the use of antibiotics is currently a major concern; however, existing literature on this issue remains insufficient. Therefore, to advance research in this area, this study utilizes data from 988 questionnaires collected across 9 provinces in China and employs the 3SLS systematic estimation method. It constructs an analytical framework to explore the mechanisms through which policy advocacy (PA) influences regulating antibiotics use (RAU) among meat duck farmers. Specifically, the study examines two pathways: " PA - public opinion pressure perception (POPP) - RAU" and " PA - moral responsibility (MR) - RAU." Additionally, it explores the potential mechanisms through which PA impacts RAU among farmers. The results show that PA (Coef = 0.070, SE = 0.014) can promote RAU by increasing the level of POPP (Coef = 0.173, SE = 0.091). PA (Coef = 0.351, SE = 0.028) can also promote RAU by enhancing MR (Coef = 0.239, SE = 0.035). Meanwhile, this study introduces Internet use (IU) and reputational incentives (RI) as moderating variables to analyze their role in moderating the impact of PA on RAU. It was demonstrated that IU (Coef = 0.088, SE = 0.016) significantly enhances farmers' awareness of the value of RAU and amplifies the impact of PA on MR. However, IU (Coef = −0.017, SE = 0.008) was found to inhibit the effect of PA on POPP. RI fully satisfies farmers' need for " honor " and enhances the effectiveness of PA in promoting both POPP (Coef = 0.009, SE = 0.002) and MR (Coef = 0.058, SE = 0.004). Finally, the study proposes that the government expand PA channels, innovate methods, and combine online outreach with demonstrations to improve farmers' awareness of antibiotic use and address their reputational needs.

1. Introduction

Since the discovery and widespread recognition of antibiotics' significant for human survival, they have quickly been adopted in livestock farming. In 1963, approximately 1000 t of antibiotics were used in livestock farming [1], but the production and use of veterinary antibiotics were not regulated at that time. Since the early 1990s, awareness has grown regarding the issues of food and environmental pollution and drug resistance caused by veterinary antibiotics [2]. Specifically, the overuse of antibiotics by farmers, often disregarding instructions or veterinarian-recommended dosages, has led to antibiotic residues in livestock products, adversely affecting consumer health and hindering the development of the food supply chain in international trade [3–6]. Moreover, excess antibiotics are directly discharged into water or soil through livestock faeces, polluting the ecological environment [7–9]. Drug-resistant bacteria in livestock can cause infections in humans [10], which are more challenging to treat than non-drug-resistant bacterial infections [11–13], leading to regional labor losses and increased healthcare burdens [14,15]. According to the World Bank, antibiotic residues and resistance reduce global GDP by 1.1–3.8 %. Therefore, promoting the regulated use of antibiotics by farmers has become an urgent issue that needs to be addressed [16,17].

Developed countries were the first to address the misuse of antibiotics in livestock farming, implementing a series of policy measures to reduce the use of veterinary antibiotics. For example, the European Union has established a strict regulatory framework, encompassing

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strict procedures for regulating the production and use of medicines. This framework includes mechanisms to raise farmers' awareness of the correct use of medicines, fosters close links between veterinarians and their clients, and ensures that veterinary services and technical advice are readily available to farmers [18–21]. In the United States, antibiotics are no longer used as growth promoters for livestock, and the regulation of antibiotics in livestock feed and drinking water has been significantly strengthened [22]. These measures demonstrate that the government plays the most crucial role as an external force in curbing the misuse of antibiotics by farmers.

China is the world's largest producer of livestock, with meat production exceeding 93 million tonnes in 2022, according to the Chinese Bureau of Statistics. Simultaneously, China is the world's largest producer and consumer of antibiotics, producing more than 16 million tonnes annually, with 52 % consumed in the livestock industry [23]. By 2030, the increasing demand for meat products is expected to result in antibiotic usage in China's livestock farming being five times higher than the global average (mg/PCU) [24]. Consequently, China's livestock industry faces severe issues related to the misuse of antibiotics, which has garnered significant attention from the Chinese government.

In practice, the Chinese government regulates farmers' antibiotic usage by developing and introducing various policy tools [20,21]. These tools include mandatory measures, such as antibiotic prescription and enforcement of withdrawal periods, as well as non-mandatory measures like subsidies to improve farmers' antibiotic usage [25–27]. However, existing studies indicate that these coercive instruments and economic incentives have not yielded optimal results [28–31]. The primary reason for this is the low level of organization within China's farming sector, characterized by small-scale, dispersed smallholder farmers, which complicates effective regulation [32]. In this context, the role of advocacy is particularly crucial. The potential of policy advocacy (PA) as a non-coercive tool is often overlooked. PA can enhance farmers' knowledge of food safety and environmental protection, fostering scientific production and management concepts and values. Additionally, PA can help farmers regulate antibiotic usage by publicizing exemplary to bolster their reputational claims [33].

In summary, China's livestock industry faces a severe problem of antibiotic misuse. Long-standing regulatory and incentive policies have had limited effectiveness, underscoring the importance of PA. Moreover, the existing literature contains relatively few studies focusing on the impact of PA on regulating antibiotics use (RAU). Therefore, this study utilizes data from 988 questionnaires collected across 9 provinces in China to construct an empirical analysis framework comprising “ PA - perception of public opinion pressure (POPP) - RAU” and “ PA - moral responsibility (MR) - RAU.” A linkage model is established, and the 3SLS systematic estimation method is employed to empirically test these two pathways. Additionally, this study introduces two moderating variables, Internet use (IU) and reputational incentives (RI), to explore their moderating roles in the impact of PA on RAU. The findings will provide a theoretical basis for formulating and implementing publicity policies concerning RAU. This will enhance meat-borne food safety, reduce farming pollution, and promote the high-quality development of the livestock industry.

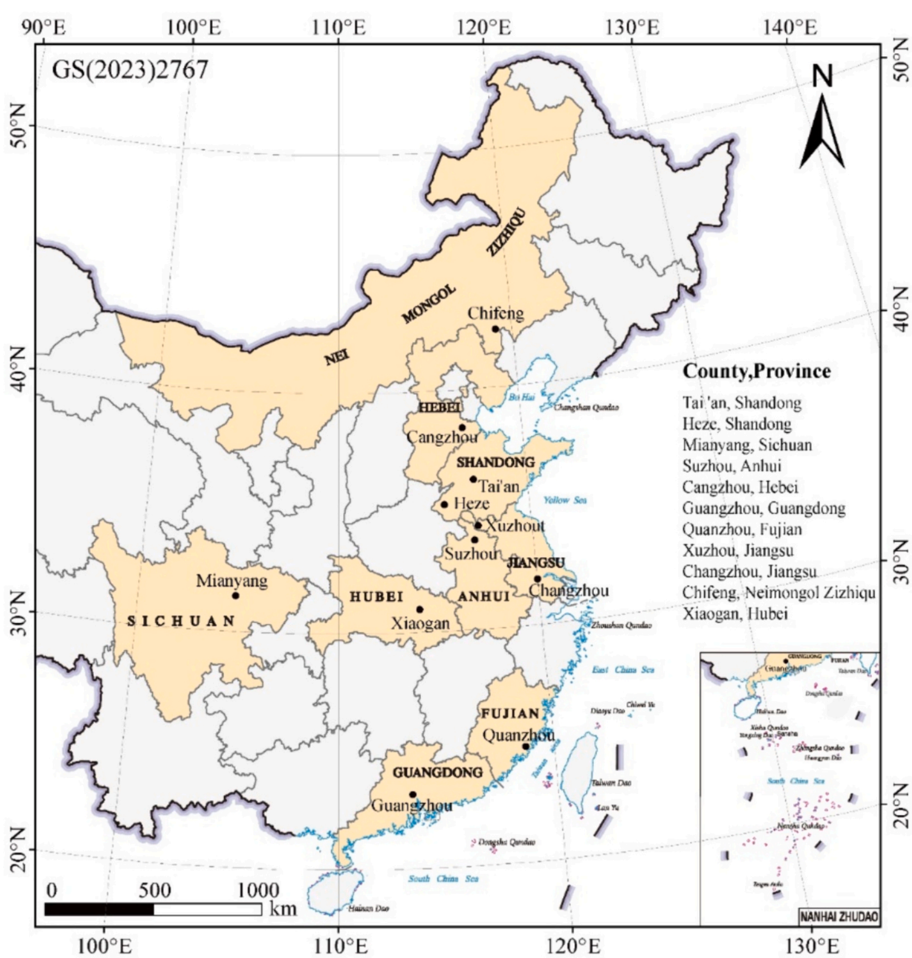

Fig. 1. Distribution of the sample areas (Source: National Surveying and Mapping Geographic).

2. Materials and method

2.1. Study sites, sampling, and participants

The data used came from field research conducted from October to December 2022 in 9 provinces, including Shandong, Sichuan, Anhui, Hebei, Guangdong, Fujian, Jiangsu, Nei Mongol, and Hubei (Fig. 1). To ensure data quality, the research team first conducted a pre-survey in Changzhou City, Jiangsu Province. Based on the pre-survey, the questionnaire was modified, and online professional training was provided to all enumerators. These provinces were chosen because they are the main meat duck-producing areas in China, with a total production of 3.078 billion meat ducks in 2022, accounting for 76.91 % of China's total meat duck production. These areas feature larger-scale and denser farming operations and represent typical behavior of meat duck farmers. Additionally, these regions include both large-scale farming enterprises and numerous small-scale farms, which have a lower degree of farming standardization, higher incidence of epidemics, and a greater tendency to increase antibiotic use. Reports indicate higher positive rates of DuCV, DAstV, DHAV, GoAstV, MDPV and RA in meat ducks in these provinces. For example, Shandong Province was a key area for DHAV infection, accounting for 60.7 % of total detections, and all other duck viruses were also detected in high numbers in Shandong.

As meat duck farming in China operates under a contract farming model, this study relied on the experimental stations and leading enterprises of the China Waterfowl Industry Technology System in each province. 15 waterfowl farmers were randomly selected by these experimental stations and enterprises in each region through stratified and random sampling. The questionnaires and interviews were conducted by a team of enumerators consisting of sales representatives from these collaborating experimental stations and enterprises. A total of 1079 questionnaires were distributed, and 988 valid questionnaires were obtained, resulting in a response rate of 91.57 %.

2.2. Variable selection

2.2.1. Dependent variables

Whether or not farmers regulate the use of antibiotics is the dependent variable in this study. Previous literature has characterized farmer behavior mainly based on behavioral decisions and the extent of their actions. In this study, we measured the regulated use of antibiotics by setting a specific question in the questionnaire, in accordance with the actual situation of the farmers and referring to relevant research [34,35]. The question was: “When setting the dosage of antibiotics, do you base it on the instructions for use, reduce the use (including the use of micro-ecological preparations, acidifiers, and other alternative medicines), or overdose (including the use of banned antibiotics)?” Farmers who chose to use antibiotics according to the instructions or reduced the dosage were assigned a value of 1, while those who overdosed were assigned a value of 0. Antibiotics used by farmers in the sample area mainly include tetracyclines, quinolones, sulfonamides, and macrolides, with frequently detected banned antibiotics including chloramphenicol and nitrofurans. This study incorporated these banned antibiotics into the questionnaire to identify farmers using banned antibiotics if they selected these options. Additionally, to measure the amount of antibiotics used by the farmers, the difference between the standard dose and the actual dose was recorded in the questionnaire. Farmers who reported an actual dose exceeding the standard dose were considered to have overused antibiotics.

2.2.2. Independent variable

PA, POPP, and MR are the core explanatory variables of this study. The Chinese government is the main body responsible for promoting the RUA [36]. In practice, the government typically employs visits, leaflets, TV advertisements, bulletins, slogans, and WeChat circles to promote RUA, which requires a certain amount of resources. The greater the investment, the stronger the PA and the more effective its impact. In this study, we measured PA through farmers' perceptions of the government's advocacy efforts. Specifically, we asked farmers to respond to the statement: “The government's advocacy efforts on the regulated use of antibiotics are very strong, “ using a five-point Likert scale ranging from strongly disagree = 1 to strongly agree = 5.

Regarding the measurement of POPP, most existing studies have measured it from the perspective of the number of reports on related content in newspapers and magazines. However, in rural areas of China, the POPP on farmers primarily comes from fellow villagers and other farmers in the same industry [37,38]. Therefore, this study measures POPP through farmers' responses to the question: “Will excessive or illegal use of antibiotics be condemned by fellow villagers and other peers?” If the response is yes, a value of 1 is assigned; otherwise, the value is 0 [39].

MR originates from one's own norms and reflects an individual's sense of responsibility and moral attribution for the adverse consequences of their behavior [40]. Therefore, this study draws on existing literature regarding the measurement of MR among farmers and assesses their sense of MR through their responses to the question: “ Do you have a responsibility to regulate the use of antibiotics in order to protect the environment and the health of consumers?” The survey employed a five-point Likert scale, ranging from strongly disagree = 1 to strongly agree = 5 [41].

2.2.3. Control variables

It has been shown that farmers' personal characteristics, family characteristics, and business characteristics influence their behavior [42–45]. Therefore, to control for other factors that may affect farmers' RAU, this study includes personal characteristics (such as age, education level, health, farming experience, and risk preference), family characteristics (such as annual household income), and business characteristics (such as farming scale and farming area) as control variables. Additionally, to account for the impact of other policy measures, the intensity of penalties is introduced as a control variable. According to the statistical analysis table (Table 1), a certain percentage of farmers exhibited irregular antibiotics use (13.30 %), and the levels of PA, POPP, and MR were relatively high, with mean values of 3.930, 0.809, and 4.038, respectively. Furthermore, the intensity of governmental penalties for irregular use of antibiotics was also substantial, with a mean value of 3.965. The available data indicate that the average age of the farmers was about 45 years, and their education level was at junior high school, suggesting relatively low educational attainment. Additionally, the farmers had been engaged in meat duck farming for an average of six years, with an annual output exceeding 110,000 ducks, indicating substantial experience and specialization in their farming practices.

2.2.4. Moderator variables

In this study, IU and RI were introduced as moderating variables to test whether the impact of PA on RAU varies according to IU and RI. IU was measured based on farmers' responses to the question: “Do you use the Internet (including circle of friends, WeChat groups, short videos, agricultural extension apps or computer web pages) to obtain information about antibiotic use?” A value of 1 was assigned for “yes” and 0 for “no.” RI was assessed through farmers' responses to the question: “The government's honorable recognition of regulated antibiotic use is very effective,” using a five-point Likert scale ranging from strongly disagree = 1 to strongly agree = 5 [46].

2.3. Research method

Integrating PA, POPP, MR and RAU into the same analytical framework requires careful consideration of potential endogeneity issues in the econometric model. Endogeneity can manifest in two main ways: first, there may be unobservable variables that simultaneously influence MR and RAU; and second, there may be a bidirectional causal

Table 1
Descriptive statistical analysis of variables.

Variables	Assignment of variables	Mean	S.E.
Dependent variable			
RAU	Yes = 1, No = 0	0.867	0.339
Independent variables			
PA	The government's advocacy efforts on the regulated use of antibiotics are very strong. (Strongly disagree = 1—strongly agree = 5)	3.930	1.006
POPP	Will excessive or illegal use of antibiotics be condemned by fellow villagers and other peers? (Yes = 1, No = 0)	0.809	0.394
MR	Do you have a responsibility to regulate the use of antibiotics in order to protect the environment and the health of consumers? (Strongly disagree = 1—strongly agree = 5)	4.038	0.911
Control variables			
Age	Actual age (years))	45.976	8.560
Education level	Actual level of education (Primary schools and below = 1; Junior high school = 2; High school or secondary school = 3; College and above = 4)	2.305	0.714
Health situation	Actual physical health status (Poor = 0, Fair = 1, Good = 2)	1.867	0.357
Annual family income	Gross annual family income (Yuan)	18.469	21.392
Farming experience	Time engaged in meat duck farming (years)	6.669	4.382
Farming scale	Annual output of meat ducks (10,000 birds)	11.580	13.484
Farming area	Area of land owned by farmers (acres)	9.423	10.576
Penalty intensity	Strong government penalties for excessive or illegal use of antibiotics? (Strongly disagree = 1—strongly agree = 5)	3.965	1.083
Risk appetite	How do you choose between two projects, one making a solid 20,000 yuan and the other making 30,000 yuan or losing 10,000 yuan? (A solid 20,000 yuan = 1, both = 2, make 30,000 yuan or lose 10,000 yuan = 3)	2.134	0.740
Instrumental variable			
Training in antibiotic use	Have you attended training on antibiotic use?(Yes = 1, No = 0)	0.759	0.428
Moderator variable			
IU	Whether or not the Internet is used to obtain information on antibiotic use? (Yes = 1, No = 0)	0.648	0.478
RI	Honorable mentions from the government work well? (Yes = 1, No = 0)	3.553	1.155

Note: 1-yuan RMB = 0.1370 USD.

relationship between MR and RAU, where RAU could also increase MR. Failure to address these endogeneity issues may lead to biased estimates and hinder the accurate analysis of how PA affects the regulated use of antibiotics by farmers.

Therefore, following the study of Scharf and Rahut [47], this study employs the 3SLS method to explore the mechanism through which PA influences RAU. 3SLS is a full information method for simultaneous equation models that utilizes all available information to estimate all equations within the model. It involves using the estimation errors from 2SLS (two-stage least squares) to construct a covariance matrix of the model's random disturbances, which enables generalized least squares estimation of the entire model. Joint equations can be estimated using either single-equation estimation, where each equation is estimated separately, or systematic estimation, where the entire set of equations is estimated simultaneously. While single-equation estimation may overlook potential correlations between disturbance terms of different equations, systematic estimation addresses this issue and is more efficient. Given the potential correlation between disturbance terms in this study's system of simultaneous equations, the 3SLS method is employed for estimation.

The linkage equations are as follows:

$$\begin{cases} R = a_0 + a_1F + a_2E + a_3C_R + \varepsilon_R \\ F = b_0 + b_1X_F + b_2C_F + \varepsilon_F \\ E = c_0 + c_1X_E + c_2C_E + c_3Z_E + \varepsilon_E \end{cases} \quad (1)$$

In Eq. (1), R represents the behavior of farmers to regulate the use of antibiotics, F represents the POPP, E represents the sense of MR, X_F represents the effect of PA on the perception of POPP, X_E represents the effect of PA on the sense of MR, C_R represents the control variable affecting the regulated use of antibiotics by the farmers, C_F represents the control variable affecting the POPP, and C_E represents the control variable affecting the MR, and Z_E represents the instrumental variable for farmers' sense of MR. a_0, b_0, and c_0 denote the intercepts, a_1, a_2, a_3, b_1, b_2, c_1, c_2, and c_3 are parameters, and ε_R, ε_F, and ε_E are error terms.

This study draws on the study of Gai et al. [48], which used training in antibiotic use as an instrumental variable for MR. Instrumental variables need to fulfill two conditions: first, they must be correlated with MR, and second, they must be uncorrelated with the model's error term. Farmers who have participated in antibiotic use training are expected to have a more comprehensive understanding of the reasons, policies, and technologies related to regulated antibiotic use, thereby enhancing their sense of MR. However, participation in training does not mean that farmers will regulate antibiotic use, nor does it have a direct impact on their regulated use of antibiotics.

3. Results

3.1. Baseline model estimation results

3.1.1. Perturbation term correlation test

When analyzing a system of joint equations containing endogenous variables, single-equation estimation using 2SLS ignores the potential correlation between the error terms of the equations. Using 3SLS addresses this limitation, resulting in more consistent and effective estimates [49]. In this study, a correlation test of the error terms for each equation in the system of joint equations specified in Eq. (1) was conducted. The results, presented in Table 2, show that the correlations between the error terms are significant at the 1 % statistical level. Therefore, it is both reasonable and necessary to use 3SLS for estimation in this study.

3.1.2. The results of the joint 3SLS estimation

The results of the 3SLS estimates are presented in Table 3, and the results with instrumental variables are shown in Table 4. Columns (1)–(3) display the baseline regression results for the joint equation. Column (2) represents the effect of PA on POPP. According to the estimation results, PA positively affects the level of POPP, indicating that POPP becomes more pronounced with the increase in PA. Column (3) represents the effect of PA on MR. The results show that PA positively affects MR, meaning MR increases with the increase in PA. Column (1) shows the effect of POPP and MR on RAU. The results indicate that both POPP and MR positively influence RAU. Therefore, after adequately

Table 2
Results of the correlation test for joint equations.

Variables	RAU	POPP	MR
RAU	1.00	–	–
POPP	0.311***	1.00	–
MR	0.381***	0.300***	1.00

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

Table 3
3sls regression results on the impact of policy advocacy on farmers' regulated use of antibiotics.

Variables	RAU (1)	POPP (2)	MR (3)
PA	–	0.074***	0.402***
		(0.014)	(0.027)
POPP	0.411***	–	–
	(0.090)		
MR	0.170***	–	–
	(0.035)		
Age	0.001	−0.003**	−0.002
	(0.001)	(0.001)	(0.003)
Education level	–	−0.036**	−0.025
	–	(0.018)	(0.033)
Health situation	0.031	0.052	0.404***
	(0.030)	(0.034)	(0.065)
Annual family income	–	–	0.258***
			(0.036)
Farming experience	−0.008***	−0.023***	0.002
	(0.003)	(0.003)	(0.005)
Farming scale	−0.003***	−0.000	−0.002
	(0.001)	(0.001)	(0.002)
Farming area	–	0.064***	−0.165***
		(0.015)	(0.029)
Penalty intensity	−0.043***	0.023*	0.178***
	(0.015)	(0.013)	(0.025)
Risk appetite	–	–	0.275***
			(0.030)
_Cons	−0.002	0.580***	0.217
	(0.112)	(0.128)	(0.264)
Observations	988	988	988
R-sq	0.121	0.154	0.448

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

Table 4
3sls regression results with the inclusion of instrumental variables.

Variables	RAU (4)	POPP (5)	MR (6)
PA	–	0.070***	0.351***
		(0.014)	(0.028)
POPP	0.173**	–	–
	(0.091)		
MR	0.239***	–	–
	(0.035)		
Age	0.001	−0.003**	−0.003
	(0.001)	(0.002)	(0.003)
Education level	–	−0.046**	−0.020
		(0.018)	(0.032)
Health situation	0.175	0.054	0.409***
	(0.030)	(0.034)	(0.065)
Annual family income	–	–	0.238***
			(0.035)
Farming experience	−0.013***	−0.024***	0.001
	(0.003)	(0.003)	(0.005)
Farming scale	−0.002***	−0.000	−0.002
	(0.001)	(0.001)	(0.002)
Farming area	–	0.069***	−0.175***
	–	(0.015)	(0.029)
Penalty intensity	−0.059***	0.026**	0.195***
	(0.015)	(0.013)	(0.025)
Risk appetite	–	–	0.291***
			(0.030)
Training in antibiotic use	–	–	0.284***
			(0.053)
_Cons	0.037	0.611***	0.169
	(0.114)	(0.129)	(0.262)
Observations	988	988	988
R-sq	0.155	0.155	0.443

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

controlling for the correlation between POPP, MR and the perturbation term of RAU, both POPP and MR were found to positively and significantly influence RAU. These estimated results preliminarily verify the impact paths of "PA - POPP - RAU " and "PA - MR - RAU ".

Columns (4) to (6) display the regression results of the joint equation with the addition of instrumental variables. Column (6) shows the results of the first stage of instrumental variable regression. According to the results of the DWH endogeneity test for MR, the F-value is 107.729, and the null hypothesis that MR is an exogenous variable is rejected at the 1 % statistical level, indicating it is considered to be an endogenous variable. The first stage regression results show that antibiotic use training (instrumental variable) is correlated with MR (potential endogenous variable) and is significant at the 1 % statistical level. Based on the requirement for valid endogenous instrumental variables [50], the instrumental variable used in this study has an F value of 23.90, indicating that antibiotic use training is appropriate as an instrumental variable for MR and that there is no issue of weak instrumental variables. Therefore, compared with the benchmark regression results, the 3SLS estimation results with instrumental variables once again verified the impact paths of " PA - POPP - RAU " and " PA - MR - RAU ", making the identification of causal relationships more accurate.

As can be seen from column (6) of Table 4, the effect of PA on MR is positively significant at the 1 % statistical level, indicating that PA can promote farmers' deeper and more comprehensive understanding of the economic, social and ecological benefits of RAU, leading to a more positive evaluation of RAU and resulting in a stronger sense of MR. In column (5) of Table 4, the effect of PA on POPP is positively significant at the 1 % statistical level, indicating that stronger PA can foster a public opinion atmosphere within villages and the farming industry that encourages RAU and denouncing illegal or excessive use. This makes the POPP among farmers more pronounced. In column (4) of Table 4, both POPP and MR positively influence farmers to RAU, indicating that farmers under greater POPP are more likely to RAU. This probability increases with enhanced publicity and the strengthening of public opinion within the village and industry. The government effectively transmits this pressure to the farmers, thereby pushing them to RAU [51].

3.2. *Robustness test*

In order to test the robustness of the estimation results of 3SLS, this study is based on the estimation of 3SLS by adding instrumental variables, and then the estimation is carried out again after 200 sample data are randomly selected and excluded from the sample, and the results are shown in Table 5. According to the results of the robustness test, after 200 sample data were randomly selected and excluded, the paths of " PA - POPP - RAU " and " PA - MR - RAU " still exist, which are consistent with the results in Table 5. The results of the 3SLS estimation are

Table 5
Robustness test results.

Variables	RAU	POPP	MR
PA	–	0.069***	0.325***
		(0.014)	(0.030)
POPP	0.716***	–	–
	(0.080)		
MR	0.124***	–	–
	(0.029)		
Training in antibiotic use	–	–	0.215***
			(0.08)
Control variables	Controlled	Controlled	Controlled
_Cons	0.059	0.367**	0.031
	(0.118)	(0.129)	(0.277)
Observations	788	788	788
R-sq	0.146	0.136	0.520

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

reliable.

3.3. Moderating effects test

There are three main modes of policy dissemination in China: internal systematic dissemination, media-mediated dissemination and direct public dissemination. Internal systematic dissemination refers to top-down or bottom-up dissemination within government agencies, relying on administrative organizational structures. Media-mediated communication uses the media as a medium to disseminate relevant policies. Direct public communication is a one-way communication model in which the government engages in direct communication with the public [52]. Media-mediated communication is the main mode of communication for PA to RAU, followed by direct public communication. Media-mediated communication and the existence of various of media communication channels have different characteristics and irreplaceability, so in the choice of policy communication channels, one or more communication channels can be chosen [53]. With the booming digital economy and the rapid spread of the Internet in rural areas, farmers have also become inseparable from the Internet in their production and life and have extensive access to policy information through the Internet. Compared to traditional media such as television, newspapers, books, and magazines, the Internet's emerging circle of friends, public numbers, short videos and other self-media in the PA has a more comprehensive form of dissemination and more rapid dissemination speed. Its "superspatial" nature is a breakthrough in the time and geographical limitations, achieving the storage and real-time dissemination of policy information [54,55]. Therefore, the Internet is playing an increasingly important role in PA, which can further convey policy messages and optimizing the effectiveness of PA.

Reputation is an important ideological capital for farmers [56], creating implicit incentives for their behavior by serving as a signaling and identifying agent. A good reputation can enhance farmers' resource mobilization and subjective motivation. According to the theory of reputational utility, good relationships and the perception of respect can intrinsically incentivize individuals [57]. In the context of PA for RAU, commending and publicizing outstanding farmers serves as a form of RI, during PA efforts is a form of RI stimulating farmers' initiative and serving as a demonstration. This approach amplifies the effect of PA and incentivizes farmers to RUA.

Based on the above analysis, this study introduced IU and RI as moderating variables in analyzing the impact of PA on RAU. The interaction terms between PA and IU, as well as between PA and RI, were constructed and added to the linkage model with instrumental variables for estimation. The results of this estimation are shown in Table 6.

As shown in Table 6, POPP and MR had a significant effect on the regulated use of antibiotics by farmers, which was consistent with the results of the benchmark regression. The interaction term between PA and IU had a significant negative effect on POPP and a significant positive effect on MR. The interaction term between PA and RI had a significant positive effect on both POPP and MR. This suggests that the impact of PA on RAU is influenced by IU and RI to some extent. The use of the Internet has made farmers more aware of the value of RAU, thus increasing the impact of PA on MR [58]. However, IU inhibited the effect of the Internet on POPP to a certain extent. The possible reason for this is that POPP mainly comes from interpersonal interactions and communication in reality, and online communication might attenuate their perception of the atmosphere of public opinion in society. RI fully caters to the "honor" needs of farmers, and through the promotion of outstanding farmers' representatives, it satisfies farmers' reputational claims while playing a demonstrative role in raising their sense of MR, thus optimizing the effectiveness of PA [59].

Table 6
Moderating effect test results.

Variables	POPP	MR	RAU
PA * IU	−0.017** (0.008)	0.088*** (0.016)	–
POPP	–	–	0.293*** (0.081)
MR	–	–	0.206*** (0.044)
Training in antibiotic use	–	0.033*** (0.058)	–
Control variables	Controlled	Controlled	Controlled
_Cons	0.656*** (0.127)	1.187*** (0.222)	0.173 (0.131)
Observations	986	986	986
R-sq	0.145	0.371	0.200
PA * RI	0.009*** (0.002)	0.058*** (0.004)	–
POPP	–	–	0.214** (0.089)
MR	–	–	0.173*** (0.044)
Training in antibiotic use	–	0.147*** (0.055)	–
Control variables	Controlled	Controlled	Controlled
_Cons	0.743*** (0.125)	0.827*** (0.192)	0.138 (0.111)
Observations	988	988	988
R-sq	0.216	0.158	0.472

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

4. Discussion

4.1. Discussion of empirical results

The misuse of antibiotics in the livestock industry can lead to the spread of antibiotic resistance and environmental pollution, making the regulation of antibiotic use an urgent priority [3,7,16]. This is particularly challenging for developing countries that rely heavily on livestock farming, as they face greater constraints in veterinary resources and regulatory capacity compared to developed countries, thus making the need to address antibiotic misuse even more pressing [60]. For China, a major player in the livestock industry, understanding the impact and mechanisms of PA on RAU is crucial. Given the limited effectiveness of the current punitive and incentive-based measures, clarifying these mechanisms is vital for further reducing antibiotic misuse, protecting consumer health, and preserving the environment.

Similar to the findings of Bechini et al. [61] and Xiong et al. [62], this study verifies the positive roles played by POPP and MR in RAU in rural areas. It demonstrates that moral risks associated with antibiotic use by farmers can be mitigated by strengthening the POPP in rural areas and enhancing farmers' sense of MR. Additionally, this study introduces IU and RI as moderating variables to analyze their role in moderating the impact of PA on RAU.

First, this study explores the pathway of" PA - POPP - RAU ". PA is typically used to announce and disseminate public policy decisions, detailing their content and implementation methods [63], and serves as a significant mode of policy execution. PA can monitor social dynamics and shape individual opinions and attitudes by influencing public opinion [64]. PA often carries a bias, promoting a particular policy or concept to encourage conformity while discouraging non-conforming behaviors. This helps the public to form an objective understanding of policy or concept, clarifies the scope of permitted and sanctioned behaviors, and creates a favorable environment for policy implementation through public opinion and individual behavior supervision [65]. From the perspective of farmers, they learn about RAU through television, the Internet, newspapers, books, and magazines, and such publicity subtly influences them. This leads to the formation of a social opinion environment and atmosphere in rural areas and the industry that positively evaluates RAU and negatively evaluates excessive or illegal use. In a long-term public opinion environment and atmosphere, the effects of PA are enduring, exerting a continuous influence on farmers. As individuals form perceptions based on current information through complex computational reasoning, the government's long-term advocacy of RAU is internalized by farmers. This perception influences their antibiotic use behavior [66]. Therefore, PA can have a sustained effect on farmers' behavior through POPP, meaning PA impacts on farmers' behavior to RAU through POPP.

Secondly, the study explores the path of "PA - MR - RAU ". In addition to communicating specific policy measures, PA also conveys values and increases MR. By promoting the economic, social and environmental values of RAU, PA helps farmers realize that RAU is both economical and necessary. This awareness fosters a sense of responsibility to RAU and positively evaluate the results and values of RAU [67]. According to social psychology, farmers' behaviors and psychological motivations during the production process are influenced by external factors. The social norms communicated through PA exert soft constraints on farmers' behaviors, shaping their sense of MR. This guides farmers' moral judgement standards to gradually align with socially accepted norms and cultivates the value of "doing the right thing", forming a strong sense of MR [68,69]. Compared to the effect of perceived external opinion pressure, moral responsibility serves as an intrinsic motivator for behavior [70]. Studies have shown that MR can significantly influence individual behavior [71,72]. In actual production, when information asymmetry exists between farmers and consumers, or between farmers and the government, farmers may engage in moral risks, violating regulations or overusing antibiotics in pursuit of greater benefits. In such cases, MR acts as a constraint on farmers' behavior. Although farmers' behavior may change with time and environment shifts, MR continues to influence their actions [73,74]. Additionally, PA increases farmers' awareness of the negative impacts of non-compliance or overuse of antibiotics, motivating them to take altruistic measures to avoid possible penalties and reduce their internal sense of guilt [75].

Third, the study explores the moderating roles of IU and RI. With the continuous development of China's digital economy, the Internet has become an essential channel for farmers to obtain information in modern agricultural development [76]. It has been shown that IU can facilitate farmers' choice of green production behaviors and improve their productivity [77–79]. In the context of antibiotic PA, the Internet serves as a crucial communication medium due to its advantages of high efficiency, real-time access, and low cost compared to traditional media [80,81]. On the one hand, relevant policies can be rapidly disseminated through villagers' network exchange groups and farmers' network exchange groups, helping farmers form an objective understanding of these policies or concepts. This quick dissemination fosters a social opinion environment and atmosphere within the village or industry, thereby strengthening the impact of PA on the level of POPP [82,83]. On the other hand, the Internet media can graphically demonstrate the adverse consequences of illegal or excessive antibiotic use and allow concerned parties to share their personal experience. This approach leaves a deep impression on farmers and strengthens their MR [84].

At the same time, due to the characteristics of the "acquaintance society" in rural areas of China, social order and interaction norms among farmers are closely tied to the element of "reputation". Farmers' decision-making is influenced by these elements, and they are often willing to incur certain costs to maintain their reputation [85,86]. Generally speaking, farmers rely on livestock farming to achieve better living conditions. According to Maslow's theory of needs, once basic needs are met, farmers become more eager to satisfy higher-level needs such as "reputation" and "honor." Reputation claims thus become an important factor influencing their decision-making [87]. In the process of PA for RAU, RI, as a non-financial incentive, can further strengthen the guiding role of PA [88]. By publicizing and recognizing outstanding farmer representatives, the environment and atmosphere of social opinion within the village and the industry can be further enhanced, thereby stimulating farmers' sense of MR.

4.2. *Feasible countermeasures designed*

Based on the findings, this study provides some valuable insights for policymakers. Firstly, the government should actively broaden the PA channels and strengthen PA inputs. Widely publicizing the antibiotic use policy in rural areas and the aquaculture industry, while expounding the possible adverse consequences of unregulated antibiotic use, can help form a favorable public opinion atmosphere for RAU in society. Secondly, the policy of RAU should be comprehensively explained to farmers. The beneficial effects of RAU in terms of economic, ecological, and social values should be elaborated to enhance farmers' awareness and MR. This can improve the subjective initiative of farmers to RAU, thus forming an internal driving force. Thirdly, attention should be paid to the moderating roles played by IU and RI in the process of PA. On one hand, it is necessary to innovate publicity methods, strengthen online publicity, and make full use of short videos, circles of friends, and public numbers to publicize the antibiotic use policy. On the other hand, it is necessary to innovate publicity methods, strengthen online publicity, and make full use of short videos, social media circles, and public accounts to disseminate the antibiotic use policy. On the other hand, it is essential to emphasize the glory of recognition and promote outstanding farmers' representatives in the PA. This can play a demonstrative role while meeting farmers' reputational demands.

4.3. *Limitations of the study*

However, this study does have some limitations. Firstly, antibiotics can be classified into prescription and non-prescription, broad-spectrum and non-broad-spectrum, and the research in this study mainly investigated the commonly used prophylactic antibiotics for meat duck farmers without analyzing the various antibiotics in a more detailed and specific manner. Secondly, from the perspective of agricultural economics, this study primarily analyzes the mechanism of action of PA as a policy instrument and does not consider the impact of market measures such as subsidy policies, although it includes the intensity of penalties as a coercive measure in the control variables. Finally, the impact of PA is long-term in nature, and the cross-sectional data used in this study do not provide a good response to the impact of PA on the long-term use of antibiotics by farmers. These issues also provide focus and direction for future in-depth research.

5. Conclusion

The World Health Organization recognizes antibiotic residues and resistance as a global crisis. In China, the excessive or illegal use of antibiotics by farmers not only diminishes the efficacy of antibiotics and increases farming costs but also leads to residual antibiotic content in livestock, as well as excessive antibiotic levels in livestock wastes. This jeopardizes consumer health and damages the ecological environment. Therefore, RAU has become a top priority for enhancing the safety of livestock products and promoting the high-quality development of the livestock industry in China. This study utilizes data from 988 farmer surveys across 9 provinces in China. It employs the empirical analysis framework of " PA - POPP - RAU " and " PA - MR - RAU " to establish a system of joint equations. The 3SLS system estimation method is used to estimate these equations and analyze the impact and mechanisms of PA on RAU. The findings indicate that PA influences RAU through two main pathways: enhancing POPP and strengthening farmers' MR. Additionally, IU and RI play moderating roles in the impact of PA on RAU. IU weakens the effect of PA on farmers' POPP but enhances the effect of PA on farmers' MR, while RI simultaneously strengthens the effects of PA on both POPP and MR. Based on these findings, the study offers policy recommendations that could also be valuable for other developing countries facing similar farming practices and challenges.

Ethics statement

Not applicable.

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Consent for publication

Not applicable.

CRediT authorship contribution statement

Jinpeng Dong: Writing – original draft, Formal analysis, Data curation, Conceptualization. **Lina Wang:** Writing – original draft, Formal analysis, Data curation, Conceptualization. **Lingzhi Liu:** Writing – review & editing, Funding acquisition. **Yuanyuan Zhang:** Validation, Supervision, Software, Methodology. **Qiang Wu:** Writing – review & editing, Funding acquisition. **Jiajia Zhao:** Validation, Supervision, Software, Methodology.

Declaration of competing interest

On behalf of all authors, the corresponding author states that there are no competing interests to declare.

Data availability

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

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