Impact of Government Regulations and Contract Farming on Antibiotic Reduction: Evidence from Chinese Duck Farmers

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Abstract

Reducing antibiotic use in livestock farming is crucial for ensuring the safety of meat-derived food products and mitigating farming-related pollution. This study analyzes survey data from 1,031 duck farmers across nine provinces in China to assess the influence of government and buyers on antibiotic reduction among farmers engaged in contract farming method. The results indicate that both government and buyers effectively facilitate the reduction of antibiotic use among farmers. This conclusion is supported by rigorous robustness and endogeneity tests. Buyers' guidance plays a mediating role in the government's efforts to promote antibiotic reduction among farmers. Different types of regulatory measures exhibit substitutive rather than complementary relationships, indicating a lack of optimal coordination among them. Significant variations exist in the effectiveness of government and buyer interventions on antibiotic reduction based on farmers' endowment factors. These findings underscore the necessity for targeted improvements in regulatory measures to enhance their efficacy.

Keywords Government Regulations; Contract Farming; Antibiotic Reduction; Livestock Farming

1. Introduction

China is the world's largest producer of meat. As of 2022, the country's meat production reached 90 million tons, with pork, chicken, duck, and poultry egg production ranking first globally. Large-scale livestock farming provides vital sources of animal protein for consumers and significantly contribute to China's economic development and rural revitalization. Veterinary antibiotics are essential inputs in livestock farming, used for disease treatment, growth promotion, and illness prevention, ensuring the safe growth of livestock [4]. However, in pursuit of farming expansion and high production, farmers have increasingly relied on antibiotics. Statistics indicate that China produces over 160,000 tons of antibiotics annually, with 52% primarily used in the livestock industry [5]. By 2030 the increasing demand of meat products is expected to result in antibiotic usage in China's livestock farming being five times higher than the global average (mg/PCU) [6].

The abuse of antibiotics by farmers diminishes the effectiveness of these drugs and, more importantly, leads to residues in livestock and waste. Evidence indicates that antibiotic resistance can be transmitted from animals to humans, posing a serious threat to human health [9]. This exacerbates public health risks by facilitating the spread of antibiotic-resistant pathogens, which can also result in significant economic losses [7,8]. The World Health Organization has identified antibiotic resistance as one of the top 10 global public health threats [10-13]. Additionally, antibiotic residues have been found in soil and marine environments, contributing to environmental hazards [14,15]. As a result, the misuse of antibiotics not only worsens resistance and endangers public health but also disrupts ecological balance [16]. According to the World Bank, antibiotic residues and resistance have led to a global GDP reduction of 1.1-3.8% [17]. Therefore, it is crucial to reduce antibiotic use in livestock farming to enhance product safety and promote high-quality development in animal husbandry, particularly in China.

Based on the experience of developed countries in antibiotic control, regulatory tools are recognized as the primary means to achieve antibiotic reduction in livestock farming [17,18]. The most important part of these regulatory tools includes a series of measures and mechanisms implemented by governments to reduce antibiotic residues in food and control farming pollution. Existing research typically categorizes these government-initiated tools into three types: penalty measures (e.g. regulations on antibiotic use and enforcement penalty), incentive strategies (e.g. financial subsidies and recognition awards) and guiding approaches (e.g. policy promotion and technical training). Previous studies have investigated how different government tools affect farmers' adoption of antibiotic reduction [19,20]. Among these tools, penalty measures generally show better results compared to incentive and guiding ones [21]. However, the effectiveness of penalty policies towards the antibiotic sector in China remains insufficient, reflected by weak antibiotic regulations and enforcement [22], for example, the relatively low cost of non-compliance for farmers who abuse antibiotics [23-24]. Economic incentives can enhance farmers' motivation to use antibiotics in a more responsible manner [25], thereby enhancing the overall effectiveness of incentive policies [26]. However, the practical effectiveness of economic incentives requires further optimization [27]. In contrast, guidance tools are becoming increasingly important in promoting antibiotic reduction in livestock farming. Promotional and training-focused guiding policies can raise farmers' awareness about food safety and environmental protection to help them adopt scientific production practices [28]. Additionally, guiding policies that emphasize reputation can appeal to farmers' desire for esteem, thus motivating them to reduce antibiotic use in livestock farming [28].

Another key component in promoting antibiotic reduction is contract farming, which involves agreements between farmers and buyers (such as processors and cooperatives) that stipulate conditions for the production and sale of agricultural products [29]. In China, contract farming is a crucial method of production in the livestock sector and plays a vital role in promoting antibiotic reduction. For example, buyers provide farmers with essentials such as production materials and loans through contract farming, alleviating productivity and liquidity constraints and enhancing their capacity for agricultural investments [31-32]. Additionally, this support establishes strict quantity and quality standards [33-34], compelling farmers to adhere closely to these standards in their antibiotic use. Furthermore, contract farming enhances farmers' understanding of antibiotics by providing education, training, and ongoing guidance, thereby increasing the likelihood of reducing antibiotic usage [30].

Existing research has explored the role of government measures and contract farming in antibiotic usage reduction. However, previous studies tend to be limited in scope, focusing on only one or two types of government measures while potentially overlooking other significant ones that could be essential. Existing research on contract farming has primarily concentrated on its economic impacts on farmers' participation in agricultural contracts [31-32,35-37] and neglected its potential influence on antibiotic reduction. China is the largest producer of meat ducks in the world, according to statistics from the China Waterfowl Industry Technology System, accounting for 80% of global production and reaching 4.68 billion ducks in 2022. Despite the importance of the duck industry, there is a notable lack of research on antibiotic reduction within this sector.

Therefore, in order to evaluate the effectiveness of different regulatory measures, comprehensive government measures and contract farming practices, in reducing antibiotic use among duck farmers in China, this study surveyed 1,031 duck farmers across nine provinces and employed Tobit and IV-Tobit models for empirical analysis. The objectives of this study are: (1) analyzing the impact of government and buyers' measures on the reduction of antibiotic use among farmers under the contract farming method; (2) examining the mediating role of buyers in the government's efforts to reduce antibiotic use among farmers; (3) investigating the interactions between different regulatory measures; (4) assessing the differential impacts of government and buyers on farmers with varying resource endowments.

2. Theoretical analysis

2.1. Government regulatory measures

The theory of externalities forms the theoretical basis for government and buyers influencing antibiotic reduction behaviors among duck farmers [38]. During the process of duck farming, the excessive or illegal use of antibiotics by farmers can create health risks for consumers and result in environmental pollution, leading to significant negative externalities [39]. The resource allocation capacity of rural markets in China is relatively weak [40]. There is a significant information asymmetry between consumers and producers in rural areas, as consumers are unable to accurately know the extent of antibiotic use in livestock farming [41]. Consequently, relying solely on market mechanisms to address antibiotic abuse in livestock farming has its limitations. It is essential to leverage government intervention to achieve Pareto optimality in social welfare. In this context, the purpose of government intervention is to transform the social costs generated by antibiotic abuse into private costs, thereby internalizing external effects. Meanwhile, with the evolving role of the government in the development of Chinese economy, regulatory tools initiated from Chinese government have diversified. Drawing from existing research [42-44], the current study categorizes government-originated regulatory tools into three types: government guidance, government incentives, and government penalties.

Government guidance employs methods such as publicity, education and training, and technical support to establish an information allocation mechanism, thereby encouraging farmers to participate in environmental governance [42]. Given that cognitive factors greatly impact farmers' decision-making [45], providing education and training can enhance their awareness of the ecological and health risks associated with excessive or illegal antibiotic use, ultimately fostering a sense of responsibility and commitment. Such approaches increase farmers' willingness to proactively reduce antibiotic use. Additionally, regular technical support from the government improves farmers' production skills, consequently, ensures compliance with technical requirements for antibiotic reduction and promotes sustainable farming practices.

Government incentives use market mechanisms and financial measures such as investments, subsidies, and other incentives to encourage farmers to engage in environmental protection and enhance food quality and safety [46]. Such incentive measures encourage farmers to adopt antibiotic reduction practices by boosting their expected income, which motivates them to act in their profit-driven interests. Additionally, the government incentives reduce perceived risks associated with antibiotic reduction by offering subsidies and compensation to farmers, thereby mitigating production and market risks for farmers with limited technological capabilities.

A crucial aspect of government restrictions is the use of penalties, such as fines and public criticism [47], aimed at enforcing corrective actions and ensuring compliance among farmers. Stringent regulation is known to promote industry development [48]. Economic penalties decrease farmers' expected income and increase anticipated costs, dissuading short-sighted behavior and encouraging antibiotic reduction measures. Public criticism impacts farmers' production, operations, and reputation, acting as effective deterrents. While government penalties are quick and reliable, they also entail drawbacks like high costs, low efficiency, and limited incentives [49], making them preferable as a last resort in regulatory strategies.

Based on the above, the following hypotheses are proposed:

H1a: Government guidance can facilitate antibiotic reduction among farmers.

H1b: Government incentives can facilitate antibiotic reduction among farmers.

H1c: Government penalties can facilitate antibiotic reduction among farmers.

2.2. Buyer regulatory measures

Under the contract farming method, a close relationship exists between buyers, mainly processors, and farmers. The regulatory measures employed by these buyers are similar to government regulation; however, due to the profit-oriented nature of businesses, they typically do not provide financial incentives to farmers [50]. Through analysis of contract terms during field research, this study categorizes buyer regulation methods into buyer guidance and buyer penalties.

Similar to government guidance, buyer guidance aims to eliminate information asymmetry and encourage farmers to participate in antibiotic reduction initiatives through means such as publicity, education, training, and technical guidance. Buyer penalties, on the other hand, involve regulatory policies such as fines and educational reprimands for farmers who violate antibiotic use regulations based on periodic inspection results [51]. Compared to the government, buyers maintain closer interactions with farmers. For instance, according to field research of the current study, farmers meet sales representatives from such buyers almost on a daily basis. This frequent interaction benefits the buyers in two ways. First, it allows real-time monitoring of farming conditions, thereby strengthening supervision and guidance. Secondly, it fosters strong connections between the buyers and farmers, promoting long-term cooperation [52]. Therefore, by employing contract farming, the regulatory measures of buyers are expected to play a significant role.

Accordingly, the following hypotheses are proposed:

H2a: Buyer guidance can facilitate antibiotic reduction among farmers.

H2b: Buyer penalties can facilitate antibiotic reduction among farmers.

2.3. The intermediary function of buyer

Under the tripartite mechanism involving the government, buyers, and farmers, buyers may play a mediating role. Based on transaction cost theory [53], the government's long-term oversight of farmers incurs high information and supervision costs. Additionally, ensuring farmers' understanding and compliance with policies involves significant expenses related to education and training. In the contract farming model, buyers maintain a close relationship with farmers and are dedicated to ensuring high-quality livestock. They regularly conduct inspections and communicate with farmers, which allows the government to delegate some regulatory and guidance responsibilities to these buyers [54-55]. Additionally, there is a regulatory and guidance relationship between the government and buyers. Relevant government departments conduct antibiotic testing on livestock products sold by buyers and guide these buyers in their antibiotic reduction efforts. This regulatory pressure compels buyers to enhance their guidance and supervision of farmers [56]. Accordingly, the following hypotheses are proposed:

H3a: Buyer guidance mediates the government's regulations in promoting antibiotic reduction among farmers.

H3b: Buyer penalties mediate the government's regulations in promoting antibiotic reduction among farmers.

2.4. Interaction between regulatory measures

There may be a complementary relationship between the implemented regulatory measures, as different measures can supplement and reinforce each other, thereby creating a synergistic effect [57]. The government plays a pivotal role in promoting antibiotic reduction among farmers through a combination of measures. Education and publicity enhance farmers' awareness, supported by incentive policies that demonstrate the benefits of antibiotic reduction. This encourages farmers to participate in technical training and adopt reduction practices. Simultaneously, regulatory guidance raises farmers' conscientiousness while publicizing penalty policies for non-compliance, creating pressure to adhere to regulations and participate in training efforts. Financial incentives further boost compliance by improving the economic benefits of reducing antibiotics, complemented by penalties as a deterrent and reinforcement of regulatory standards. Similarly, within buyers, guidance and penalties work synergistically to foster compliance and promote sustainable antibiotic use practices among farmers.

Accordingly, the following hypotheses are proposed:

H4a: The complementary effect of government guidance and incentives can jointly facilitate farmers' implementation of antibiotic reduction.

H4b: The complementary effect of government guidance and penalties can jointly facilitate farmers' implementation of antibiotic reduction.

H4c: The complementary effect of government incentives and penalties can jointly facilitate farmers' implementation of antibiotic reduction.

H4d: The complementary effect of buyer guidance and penalties can jointly facilitate farmers' implementation of antibiotic reduction.

3. Research methods and data

3.1. Data Source

The data used in this study were derived from on-site investigations conducted from October to December 2023 in nine major duck-producing provinces in China: Shandong, Sichuan, Anhui, Hebei, Guangdong, Fujian, Jiangsu, Neimongol Zizhiqu, and Hubei. These provinces were chosen for their significant contribution to the country's duck production, accounting for 76.91% of the total output in 2022, with a combined production of 3.078 billion ducks. The large-scale and dense duck farming practices in these provinces make the behavior of their duck farmers highly representative of the industry. These selected provinces have a longstanding tradition of duck farming. The author's team, which is part of the China Waterfowl Industry Technology System, has established experimental stations and collaborated with leading buyers across all nine provinces. These regions host both large-scale farming buyers and smaller, less standardized farms with limited biosecurity measures, making them more susceptible to increased antibiotic use.

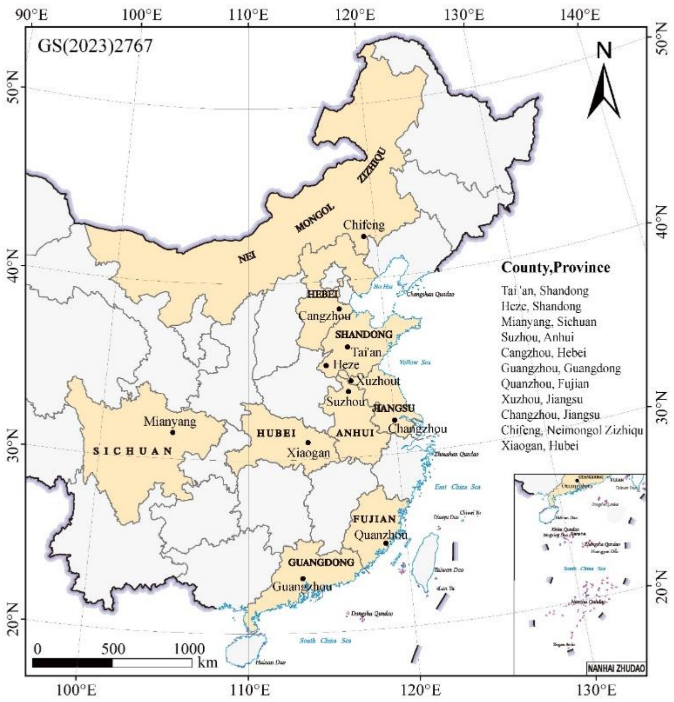

Fig. 1. Distribution of the sample areas (Source: National Surveying and Mapping Geographic)

The survey questionnaire consists of five sections covering the characteristics of the farmers, family features, operational aspects, antibiotic usage patterns, and social network features. To ensure data quality, the research team conducted a preliminary investigation in Xuzhou City, Jiangsu Province, before commencing the formal survey. Enumerators received online professional knowledge training. Leveraging the China Waterfowl Industry Technology System's experimental stations and collaborations with leading buyers across provinces, the research team randomly selected sample duck farmers from distribution lists provided by these entities. Team members and personnel from the experimental stations and leading buyers conducted interviews with the selected duck farmers. A total of 1,042 questionnaires were collected during the survey. After excluding invalid questionnaires with missing core information, 1,031 valid questionnaires were obtained, resulting in an effective response rate of 98.94%.

3.2. Variable selection

3.2.1. Farmers' antibiotic input

Drawing on existing studies and considering current farming realities, farmers' antibiotic expenditure is defined as the dependent variable [58]. The questionnaire includes a specific question: “What is your annual total expenditure on antibiotics?” Subsequently, the average antibiotic expenditure per duck is calculated by dividing the total expenditure by the number of ducks sold. This metric serves as an indicator of the extent to which farmers are reducing antibiotic usage.

3.2.2. Government regulations

This study classifies government regulations into three types: government guidance, government incentives, and government penalties.

To achieve antibiotic reduction, enhancing environmental control during the farming process, developing standardized, large-scale, and well-equipped farming practices, and scientifically selecting alternative products such as enzymes, probiotics, and antimicrobial peptides are necessary. This process requires continuous government publicity and guidance to enhance farmers' awareness of antibiotic reduction. Accordingly, the average responses to the survey questions “What is the impact of government awareness campaigns on reducing antibiotic usage?” and “What is the impact of government technical training on reducing antibiotic usage?” represent government guidance.

The “National Action Plan for the Reduction of Veterinary Antimicrobial Use (2021-2025)” proposes establishing an incentive mechanism for antibiotic reduction [59]. Since reducing antibiotic use may introduce farming risks, farmers might resist due to loss aversion. Therefore, economic incentives such as subsidies and rewards are necessary. Accordingly, the average responses to the survey questions “What is the impact of government economic incentives on reducing antibiotic usage?” and “What is the impact of government reputation incentives on reducing antibiotic usage?” represent government incentives.

According to the “National Action Plan for the Reduction of Veterinary Antimicrobial Use (2021-2025),” to promote antibiotic reduction among farmers, it is essential to strengthen the supervision of antibiotic use and impose severe penalties for violations [59]. Accordingly, the average responses to the survey questions “What is the impact of government economic penalties on reducing antibiotic usage?” and “What is the impact of government administrative penalties on reducing antibiotic usage?” represent government penalties.

The “intensity” of the government regulation is measured using a 5-point Likert scale, which reflects the surveyed farmers' perceptions of government guidance, incentives, and penalties. The specific scale is: Very small = 1, Comparatively small = 2, Moderate = 3, Comparatively large = 4, Very large = 5.

3.2.3. Buyer regulations

Similar to the indicators set for government regulations, buyer regulations are classified into two types: buyer guidance and buyer penalties.

Buyer guidance is represented by the average responses to the survey questions “What is the impact of buyer awareness campaigns on reducing antibiotic usage?” and “What is the impact of buyer technical training on reducing antibiotic usage?”

Buyer penalties is represented by the average responses to the survey questions “What is the impact of buyer economic penalties on reducing antibiotic usage?” and “What is the impact of buyer administrative penalties on reducing antibiotic usage?”

The “intensity” of buyer regulations is also measured using a 5-point Likert scale, which reflects the surveyed farmers' perceptions of buyer guidance and penalties. The specific scale is: Very small = 1, Comparatively small = 2, Moderate = 3, Comparatively large = 4, Very large = 5.

3.2.4. Instrumental variables

Given the high technical standards, implementation difficulty, and associated farming risks of antibiotic reduction, both government and buyers tend to adopt a 'target-oriented' approach. This involves prioritizing farms already capable and willing to implement antibiotic reduction measures for promotional and guidance activities, resulting in these farms receiving more policy support. To mitigate potential biases, this study employs 'distance between farms and livestock department' and 'distance between farms and buyer' as instrumental variables. The selection of these instruments is guided by two considerations: first, existing research emphasizes geographical factors as preferable in instrumental variable selection [60]; second, proximity between farms and the livestock department or buyer increases access to relevant guidance and promotional activities for antibiotic reduction, thereby meeting the requirement for correlation between instrumental variables and endogenous variables. These instrumental variables are chosen to control for endogeneity issues, ensuring accurate estimation of the impact of government and buyer guidance on antibiotic reduction behaviors among farmers.

3.2.5. Control variables

Existing research has indicated that individual characteristics, family features, and operational factors of farmers can influence their behavior [61]. Therefore, to control for other potential factors that may impact antibiotic reduction among farmers, this study incorporates personal characteristics of surveyed farmers (including age, gender, education level, health status, leadership role, farming experience, and risk preference), family features (including family labor size and family income), and operational features (including farming area, farming scale, borrowing behavior, land type, and livestock insurance) as control variables.

The meanings of variables and descriptive statistics are presented in Table 1.

Table 1 Variable definitions and descriptive statistics

Variables	Variable assignment	Mean	S.E.
Antibiotic input	Cost of antibiotic input per duck (RMB/duck)	0.585	0.583
Government guidance	The average of two types of government-guided regulatory measures.	3.958	0.853
Government incentives	The average of two types of government incentive regulatory measures.	3.784	0.999
Government penalties	The average of two types of government criticism and education regulatory measures.	3.928	0.909
Buyer guidance	The average of two types of buyer-guided regulatory measures.	3.962	0.866
Buyer penalties	The average of two types of buyer criticism and education regulatory measures.	3.859	1.026
Age	Actual age of the respondent at the time of survey.	43.956	14.485
Gender	Male=1, Female=0	0.858	0.349
Education level	Actual years of education of the respondent.	8.987	2.633
Health status	Health condition of the respondent: Poor=0, Fair=1, Good=2	2.613	0.503
Leadership role	Have you ever served as a village official? Yes=1, No=0	0.089	0.285
Farming experience	Number of years engaged in duck farming for the livestock farmer.	7.533	5.041
Risk preference	If there is a new breed with better breeding efficiency, what proportion would you allocate for breeding? 40% and below=1; 40%-80%=2; 80% and above=3	1.942	0.831
Family labor size	Number of family members engaged in duck farming.	2.952	1.163
Family income	Annual total income of the livestock farmer's household (RMB).	25.75	58.621
Farming area	The land area occupied by livestock farms (hectares)	1.086	23.844
Farming scale	Annual output of meat ducks (10,000 ducks).	10.968	13.966
Borrowing behavior	Is there any borrowing activity during the process of duck farming? Yes=1, No=0	0.275	0.447
Land type	Flatland = 1, Hills = 2, Mountainous = 3	1.391	0.618
Livestock insurance	Did you purchase livestock insurance during the process of duck farming? Yes=1, No=0	0.267	0.442
Distance between farms and livestock department	The distance from livestock farms to the nearest livestock management department	14.990	9.675
Distance between farms and buyer	The distance from livestock farms to the collaborating agricultural buyer	29.011	17.734
Province-level dummy variables	This study established dummy variables based on provincial regions, encompassing 9 provinces. Setting a specific province to 1 implies that all other provinces are set to 0.		

3.3. Estimation methods

The Tobit model is employed to examine the impact of government and buyer regulations on antibiotic reduction among livestock farmers. This study selects antibiotic input by livestock farmers as the dependent variable. Given that antibiotic input costs for livestock farmers may have zero values, representing censored continuous merged data, the Tobit model is employed to explore the influence of government and buyer regulations on antibiotic reduction. Additionally, the IV-Tobit model is applied to address potential endogeneity issues. The model is constructed as follows:

$$\begin{cases} \text{Antibiotic}^{*} = \xi_{\text{i}} X_{\text{i}} + \delta_{\text{i}} \text{Government}_{\text{i}} + \alpha_{i} \text{Buyer}_{i} + \theta_{\text{i}} \\ \text{Antibiotic} = \max(0, \text{Antibiotic}^{*}) \end{cases} \tag{1}$$

where *Antibiotic** is the latent variable, *Antibiotic* represents antibiotic input by livestock farmers. X_i is a vector of exogenous explanatory variables (e.g., age, gender, and education level). $Government_i$ represents government regulations including government guidance, government incentives and government penalties. $Buyer_i$ represents buyer regulations including buyer guidance and buyer penalties. To address potential endogeneity issues, this study introduces "The distance between livestock farms and the livestock management department" and "the distance between livestock farms and the collaborating buyer" as instrumental variables and estimates the model using the IV-Tobit model to eliminate estimation bias induced by endogeneity.

A mediation effects model is employed to analyze the potential mediating role of buyer regulations in the impact of government regulations on antibiotic reduction. The model is constructed as follows:

$$Enterprise = \delta_i x_i + \upsilon_i \tag{2}$$

$$Antibiotic^* = \xi_i^{'} X_i + \delta_i^{'} Government_i + \gamma \mathrm{Buyer} + \omega_i \tag{3}$$

where *Antibiotic**, *Internet*$_i$, *Government*$_i$ *and* X_i carry the same meanings as in Eq. (1). *Buyer* serves as the mediating variable representing buyer regulations.; δ_i is an estimated parameter; $\xi_i^{`}$ *and* $\delta_i^{`}$ are the direct effects of the independent variables on the dependent variable after controlling for the effect of the mediating variable *Buyer*; γ is estimated parameter of the mediating variable *Buyer*; υ_i and ω_i represent independently and identically distributed random error terms.

To test the synergy of various regulatory measures, interaction terms were constructed for government guidance and government incentives, government guidance and government penalties, government incentives and government penalties, and buyer guidance and buyer penalties for estimation.

Given that the impact effects of government regulations and buyer regulations on antibiotic reduction may be influenced by inherent resource endowments, and that there may be correlations among disturbance terms of different characteristic samples, we have opted to employ Fisher's Permutation Test method to construct a heterogeneity analysis model. The model is constructed as follows:

$$\begin{cases} \mathrm{Antibiotic}^* = \xi_i X_i^{\,k} + \delta_i \mathrm{Government}_i^{\,k} + \alpha_i \mathrm{Buyer}_i^{\,k} + \theta_i^{\,k} \\ \mathrm{Antibiotic} = \max(0, \mathrm{Antibiotic}^*) \end{cases} \tag{4}$$

where *k* represents the criteria for grouping including farmer’s age, educational level, farming scale and farming experience. We conduct group-by-group analysis on the interviewed subjects. The calculation results are assessed based on the empirical p-value of the inter-group coefficient differences being less than 0.05, to determine whether the impact effects of government regulations and buyer regulations on antibiotic reduction are sensitive to grouping factors at a 95% confidence level.

4. Empirical results

4.1 Benchmark regression

Before conducting the benchmark regression, a multicollinearity test was performed. The variance inflation factors (VIF) for the explanatory variables were all well below 10, indicating no issues with multicollinearity. The results of the benchmark regression, presented in Table 3, show significant negative effects of government and buyer regulations on antibiotic usage by farmers. For government regulations, a 1% increase in the intensity of government guidance, incentives, and penalties corresponded to reductions of 6.9%, 4.4%, and 5.8%, respectively, in antibiotic usage. For buyer regulations, a 1% increase in the intensity of buyer guidance and penalties led to reductions of 6.3% and 3.9%, respectively, in antibiotic usage. These findings confirm Hypotheses H1a, H1b, H1c, H2a, and H2b.

Table 2 Benchmark Regression Results

Variable name	Model 1	Mode 2	Mode 3	Mode 4	Mode 5
Government guidance	-0.069***				
	(0.006)				
Government incentives		-0.044***			
		(0.005)			
Government penalties			-0.058***		
			(0.006)		
Buyer guidance				-0.063***	
				(0.006)	
Buyer penalties					-0.039***
					(0.005)
Age	-0.001**	-0.001*	-0.001*	-0.001*	-0.001**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Gender	0.008	-0.000	0.007	0.013	0.009
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Education level	-0.001	-0.001	-0.000	-0.000	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Health status	0.005	0.001	-0.003	-0.002	-0.004
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
Leadership role	0.011	0.009	0.008	0.009	0.010
	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)
Farming experience	0.003**	0.003**	0.003***	0.003**	0.003**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Risk preference	-0.007	-0.007	-0.011	-0.011	-0.013**
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Family labor size	0.001	0.001	0.002	0.001	0.002
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Family income	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Farming area	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Farming scale	-0.002***	-0.002***	-0.002***	-0.002***	-0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Borrowing behavior	-0.017	-0.016	-0.014	-0.011	-0.011
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
Land type	-0.019**	-0.023**	-0.020**	-0.015	-0.017*
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Livestock insurance	0.020*	0.010	0.015	0.016	0.007
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
_cons	1.973***	1.734***	2.008***	1.822***	1.683***
	(0.228)	(0.232)	(0.235)	(0.226)	(0.235)
Province-level dummy variables	control	control	control	control	control
Pseudo R2	0.170	0.141	0.156	0.164	0.131
Log likelihood	-751.500	-777.842	-764.652	-757.309	-786.664
Obs	1031	1031	1031	1031	1031

Note: The table reports marginal effects with standard errors in parentheses; *, **, *** indicate significance levels of 10%, 5%, and 1%, respectively.

4.2 Robustness test

To ensure the robustness of our estimates and mitigate potential biases from uncontrollable factors, robustness tests were conducted by employing alternative econometric models and reducing the estimation sample size. These measures help verify the consistency and reliability of the findings.

4.2.1. Using alternative econometric models

The OLS model is employed to re-estimate the data, and the results are shown in Table 3. The estimates indicate that both government regulations and buyer regulations significantly promote antibiotic reduction behaviors among farmers. The estimates of control variables are also largely consistent with those from the benchmark regression. Therefore, the benchmark regression results are robust.

Table 3 Robustness Test (Alternative Econometric Models)

Variable name	Model 1	Mode 2	Mode 3	Mode 4	Mode 5
Government guidance	-0.252*** (0.022)				
Government incentives		-0.166*** (0.019)			
Government penalties			-0.214*** (0.021)		
Buyer guidance				-0.232*** (0.021)	
Buyer penalties					-0.147*** (0.020)
_cons	1.973*** (0.231)	1.734*** (0.235)	2.008*** (0.238)	1.822*** (0.229)	1.683*** (0.238)
Control variables	Control	Control	Control	Control	Control
Province-level dummy variables	Control	Control	Control	Control	Control
Adj R-squared	0.240	0.219	0.239	0.250	0.186
Obs	1031	1031	1031	1031	1031

Note: The table reports coefficients with standard errors in parentheses; *, **, *** indicate significance levels of 10%, 5%, and 1%, respectively.

4.2.2. Reduce the sample size

Considering demographic differences, elderly individuals face challenges in adopting antibiotic reduction behaviors due to disparities in physical function, cognitive ability, and technological proficiency. Farmers aged 60 and above were excluded from the sample, and the data were re-estimated, as shown in Table 4. Government and buyer regulations still significantly encourage antibiotic reduction behaviors among farmers, confirming the reliability of the benchmark regression results.

Table 4 Robustness test (Reduced Elderly Sample)

Variable name	Model 1	Mode 2	Mode 3	Mode 4	Mode 5
Government guidance	-0.069*** (0.006)				
Government incentives		-0.043*** (0.005)			
Government penalties			-0.058*** (0.006)		
Buyer guidance				-0.063*** (0.006)	
Buyer penalties					-0.038*** (0.005)
_cons	1.999*** (0.243)	1.754*** (0.247)	2.047*** (0.249)	1.847*** (0.241)	1.681*** (0.250)
Control variables	Control	Control	Control	Control	Control
Province-level dummy variables	Control	Control	Control	Control	Control

Adj R-squared	0.167	0.137	0.154	0.161	0.128
Log likelihood	-714.777	-740.627	-726.024	720.231	-748.721
Obs	961	961	961	961	961

Note: The table reports marginal effects with standard errors in parentheses; *, **, *** indicate significance levels of 10%, 5%, and 1%, respectively.

4.3 Endogeneity Test

Government guidance and buyer guidance are considered endogenous variables, and distances between livestock farms and the livestock department, as well as between livestock farms and buyers, are used as instruments to estimate their predicted values. IV-Tobit estimation is conducted according to equation (1), and the results are shown in Table 5. The second-stage Wald statistics are 3.90 and 3.65 respectively, significant at the 5% and 10% levels, indicating rejection of the null hypothesis and confirming the presence of endogeneity issues. This justifies the use of the instrumental variables approach [62]. Weak instrument tests yield first-stage F-statistics of 22.68 and 28.54, indicating a correlation between the instrumental variables—distances to the livestock sector and buyers—and the endogenous variables government guidance and buyer guidance, without indicating weak instrument problems.

Table 5 Results of Endogeneity Test

Variable name	Model 1	Mode 2
Government guidance	-0.384***	
	(0.072)	
Buyer guidance		-0.155***
		(0.046)
Control variable	Control	Control
Province-level dummy variables	Control	Control
_Cons	2.151***	1.427***
	(0.289)	(0.229)
Adj R-squared	0.345	
Wald test	3.90**	3.65*
First-stage F-statistic	22.68	28.54
Distance between farms and livestock department	-0.026***	
	(0.002)	
Distance between farms and livestock department		-0.023***
		(0.001)
_Cons	3.637***	3.497***
	(0.262)	(0.250)
Observations	1031	1031

Note: The table reports coefficients with standard errors in parentheses; *, **, *** indicate significance levels of 10%, 5%, and 1%, respectively.

In summary, within the contract farming method, government regulations and buyer regulations significantly reduce antibiotic usage in livestock farming. This conclusion remains robust after conducting tests for robustness and addressing concerns about endogeneity. The next section will explore the interaction between government and buyers, examining the dynamics between different types of regulatory measures.

4.4 Buyer as mediator

To analyze the mediating role of buyers in the process of government influence on livestock farmers' antibiotic reduction, a bias-corrected non-parametric percentile bootstrap method is employed for interval testing. Confidence intervals were set at 95%, with 5000 repetitions of sampling. The results of the mediation analysis, presented in Table 6, indicate that the 95% confidence intervals for the impact of buyer guidance under all three types of governmental regulations on antibiotic reduction do not include "0", suggesting that buyer guidance acts as a significant mediator in these effects. These findings confirm Hypothesis H3a and refute Hypothesis H3b.

Table 6 Result of bootstrap test

Variable name	Effect	Coefficients	S.E.	Confidence interval
Government guidance - buyer guidance	Mediation effect	-0.088***	0.025	[-0.138, -0.038]
	Direct effect	-0.164***	0.039	[-0.240, -0.088]
Government guidance - buyer penalties	Mediation effect	-0.005	0.028	[-0.060, 0.049]
	Direct effect	-0.246***	0.053	[-0.349, 0.144]
Government incentives - buyer guidance	Mediation effect	-0.111***	0.021	[-0.152, -0.071]
	Direct effect	-0.055*	0.029	[-0.111, 0.002]
Government incentives - buyer penalties	Mediation effect	-0.041**	0.022	[-0.084, 0.011]
	Direct effect	-0.125***	0.040	[-0.203, -0.046]
Government penalties - buyer guidance	Mediation effect	-0.106***	0.024	[-0.154, -0.058]
	Direct effect	-0.108***	0.041	[-0.189, -0.027]
Government penalties - buyer penalties	Mediation effect	-0.016	0.031	[-0.078, 0.045]
	Direct effect	-0.198***	0.056	[-0.308, -0.087]

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

4.5. Interactions among regulatory measures

To explore interactions among different types of regulatory measures, this study includes interaction terms in the analysis (see Table 7). According to the regression results, individual government regulatory measures significantly facilitate the reduction of antibiotic use among farmers. However, the interaction terms for these measures are positively significant at the 1% statistical level, contradicting the individual effects of the measures. This suggests a substitutive rather than synergistic relationship among the government regulatory measures. Additionally, the interaction terms between the two buyer regulatory measures are not statistically significant, indicating no synergistic or substitutive relationship. This implies that the various regulatory measures have not formed a cohesive synergy and do not collectively facilitate the reduction of antibiotic use among farmers. This lack of coordination may be related to the formulation and practical implementation of these policies. Therefore, hypotheses H4a, H4b, H4c, and H4d have all been refuted.

Table 7 Interactions among regulatory measures

Variable name	Model 1	Mode 2	Mode 3	Mode 4
Government guidance	-0.217***	-0.182***		
	(0.032)	(0.037)		
Government incentives	-0.039		-0.035	
	(0.027)		(0.029)	
Government penalties		-0.073**	-0.187***	
		(0.035)	(0.033)	
Government guidance * Government incentives	0.145***			
	(0.026)			
Government guidance * Government penalties		0.148***		
		(0.027)		
Government incentives * Government penalties			0.099***	
			(0.027)	
Buyer guidance				-0.243***

				(0.031)
Buyer penalties				0.012
				(0.028)
Buyer guidance * Buyer penalties				-0.014
				(0.022)
Control variable	Control	Control	Control	Control
_cons	2.036***	2.072***	2.013***	1.818***
	(0.225)	(0.228)	(0.011)	(0.229)
Province-level dummy variables	Control	Control	Control	Control
Pseudo R2	0.188	0.187	0.164	0.164
Log likelihood	-735.764	-735.848	-756.950	-757.045
Obs	1031	1031	1031	1031

Note: The table reports coefficients with standard errors in parentheses; *, **, *** indicate significance levels of 10%, 5%, and 1%, respectively.

4.6. Heterogeneity Analysis

This study assesses how endowment factors influence the effectiveness of government and buyer regulations in reducing antibiotic use among farmers. Inter-group coefficients and confidence intervals for the impact of these regulations are calculated across different groupings: age, education level, farming scale, and farming experience (see Figure 2) [63]. Significant differences in inter-group coefficients are determined based on whether the 95% confidence intervals overlap, indicating notable distinctions [64]. Fisher's Permutation test verifies the reliability of significant differences indicated by non-overlapping confidence intervals. Additionally, the study examines cases where confidence intervals partially overlap but are not completely identical (see Table 8). Age groups are categorized based on a threshold of 50 years; educational levels are divided by a threshold of 9 years (China's compulsory education duration); farming scale boundaries are set using the average annual livestock output of all samples, with a threshold of 100,000 ducks per year to differentiate between large-scale and small-scale operations; and farming experience thresholds are based on the average of all samples, with a threshold of 7 years distinguishing high and low experience levels.

The findings suggest that the impact of government and buyer regulations does not vary significantly across different age groups. The impact of government penalties and buyer guidance is more pronounced among individuals with higher education levels. Government guidance and buyer guidance are both more effective in promoting antibiotic reduction among small-scale farmers. Additionally, all types of government regulations are more effective in promoting antibiotic reduction among farmers with extensive farming experience.

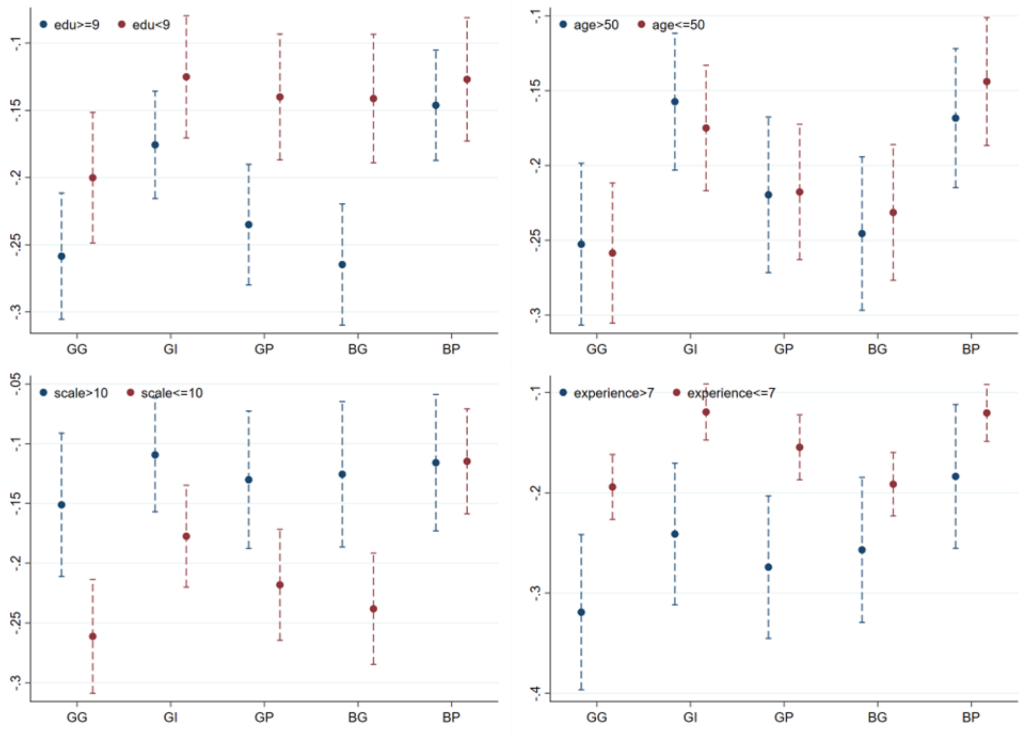

Figure 2 Inter-group coefficients and confidence intervals of government and buyers

Table 8 Heterogeneity analysis results

Variable name	Elderly	Young	High education	Low education	Large scale	Small scale	High experience	Low experience
Government guidance	-0.253*** (0.032)	-0.258*** (0.028)	-0.259*** (0.029)	-0.200*** (0.029)	-0.151*** (0.036)	-0.261*** (0.029)	-0.319*** (0.047)	-0.194*** (0.020)
Government incentives	-0.157*** (0.028)	-0.175*** (0.025)	-0.176*** (0.024)	-0.125*** (0.028)	-0.109*** (0.029)	-0.177*** (0.026)	-0.241*** (0.043)	-0.119*** (0.017)
Government penalties	-0.220*** (0.032)	-0.218*** (0.007)	-0.235*** (0.027)	-0.140*** (0.028)	-0.130*** (0.035)	-0.218*** (0.028)	-0.274*** (0.043)	-0.155*** (0.020)
Buyer guidance	-0.245*** (0.031)	-0.231*** (0.028)	-0.265*** (0.027)	-0.141*** (0.029)	-0.126*** (0.037)	-0.238*** (0.028)	-0.257*** (0.044)	-0.191*** (0.019)
Buyer penalties	-0.144*** (0.259)	-0.168*** (0.028)	-0.146*** (0.025)	-0.127*** (0.028)	-0.116*** (0.035)	-0.115*** (0.027)	-0.184*** (0.044)	-0.120*** (0.017)
Control variable	Control	Control	Control	Control	Control	Control	Control	Control
Province-level dummy variables	Control	Control	Control	Control	Control	Control	Control	Control
P-value (government guidance)	0.443		0.200		0.045		0.032	
P-value (Government incentives)	0.362		0.193		0.105		0.013	
P-value (Government penalties)	0.493		0.097		0.107		0.040	
P-value (Buyer guidance)	0.408		0.020		0.035		0.157	
P-value (Buyer penalties)	0.269		0.319		0.470		0.053	
Obs	336	695	712	319	306	725	398	633

Note: The table reports coefficients with standard errors in parentheses; *, **, *** indicate significance levels of 10%, 5%, and 1%, respectively.

5. Discussions

The results of the empirical analysis demonstrate that both government regulations and buyer regulations significantly promote antibiotic reduction among farmers, consistent with findings from earlier studies [25, 28, 30]. The study also found that among the three types of government regulations, their effects can be ranked as follows: government guidance > government penalties > government incentives, which differs from the conclusions drawn in previous literature [21]. A possible explanation for this might be that China has a comprehensive agricultural technology extension system, including traditional public agricultural technology extension and the increasingly popular online agricultural technology extension. This system naturally facilitates the dissemination of antibiotic reduction technologies and concepts, making government guidance the most effective among the three types of regulations. Government penalties enforce measures that warn and constrain farmers. Economic penalties directly lead to financial losses for farmers, while reputation penalties target farmers' concerns about their public image, creating a strong deterrent effect. Although the National Action Plan for the Reduction of Veterinary Antimicrobial Use (2021-2025) explicitly aims to establish incentives for antibiotic reduction [59], the current incentive mechanisms are not fully developed. Subsidy policies vary across regions and are difficult to implement consistently, resulting in the weakest impact from government incentives.

In terms of buyer regulations, similar to government regulations, the effectiveness of buyer guidance surpasses that of buyer penalties. The survey found that buyer staff engage with farmers nearly every day, which enhances their ability to effectively facilitate antibiotic reduction initiatives. Within the framework of contract farming, buyers act as catalysts in government-led efforts to reduce antibiotic usage. They collaborate with governmental bodies to provide technical guidance to farmers, thereby facilitating the dissemination, impact, and spillover effects of agricultural technologies, which is consistent with findings from previous research [30]. Moreover, due to the cooperative nature of their relationship with farmers, buyers prioritize improving product quality over punitive measures. As a result, they place greater emphasis on guiding farmers toward antibiotic reduction, making buyer guidance more effective than buyer penalties.

As expected, buyers indeed play a mediating role in the government's efforts to promote antibiotic reduction among farmers. Buyers primarily mediate these effects through their role in guiding regulatory practices. In the process of governmental influence on livestock farmers, buyers undertake tasks such as policy dissemination and technical training. Governmental regulations effectively facilitate antibiotic reduction behaviors among farmers through the guidance provided by buyers. However, buyer penalties did not serve as a mediating factor. In promoting antibiotic reduction in livestock farming, buyers primarily rely on measures such as technical training and policy advocacy. Implementing penalty measures could strain the cooperative relationship between buyers and farmers. Since buyers often prioritize maintaining a positive rapport with farmers to ensure ongoing cooperation and productivity, they may avoid intensifying penalty measures in response to governmental initiatives aimed at reducing antibiotic use [51]. This cautious approach regarding penalties may explain the lack of a mediating effect for buyer penalties in influencing farmers' antibiotic reduction behaviors under governmental regulations.

Contrary to expectations, there is no apparent synergy between different measures; instead, there is a clear substitution effect. In China's efforts to reduce antibiotic usage, central government policy documents do not explicitly outline reduction targets. Instead, some provincial governments establish goals focusing on overall antibiotic usage and compliance rates of inspection samples. For example, Shandong Province aims to maintain a compliance rate of over 98% for antibiotic residues in meat, eggs, dairy, and other livestock products during the '14th Five-Year Plan' period. Similarly, Henan Province targets an annual reduction of over 5% in point-of-use antibiotic quantities and over 10% in antibiotic class quantities, while also aiming to sustain a stable inspection compliance rate above 98% for pesticide and antibiotic residues. However, these targets lack specificity for each type of antibiotic, leading both government bodies and buyers to assess antibiotic usage against legally defined standard quantities. As a result, farmers may only moderately reduce antibiotic usage or may not adjust usage at all based on these standard quantities. This reliance on subjective judgments by enforcement officers and business personnel can result in inconsistent application of regulatory measures, thereby undermining their synergistic effectiveness.

Moreover, the results of the heterogeneity analysis confirm that farmers' behavior is strongly influenced by their resource endowments. For instance, farmers with higher education levels better understand the implications of government penalties, place greater emphasis on economic and reputational consequences, and are more receptive to guidance provided by buyers. Compared to large-scale farmers, small-scale farmers are more responsive to technical training and policy advocacy from both the government and buyers. This likely stems from the limited capacity and resources of small-scale farmers, who require more guidance on antibiotic reduction techniques and benefit from maintaining relationships with the government and buyers to access necessary resources. Additionally, farmers with extensive experience have longer interactions with government agencies and a deeper understanding of government regulations, which enhances their compliance with these regulations.

6. Conclusions and policy implications

This study illustrates that in the context of contract farming, livestock farmers are influenced by both government and buyers to adopt antibiotic reduction measures. The effectiveness of these regulatory measures varies, highlighting the diverse needs of farmers for technologies and policy support. Buyers play a critical mediating role, bridging the gap between government directives and farmers' practices. The substitutive relationships observed among regulatory measures suggest opportunities for improving their formulation and implementation, as well as enhancing the synergy between different measures. The heterogeneity analysis underscores the diversity among livestock farmers based on their resource endowments, providing insights for targeted regulatory improvements.

The findings from our study have significant policy implications. Given the robust effectiveness of guiding regulations, both government and buyers should intensify efforts to enhance direct education and technical guidance for livestock farmers to encourage antibiotic reduction in farming practices. Additionally, there is a need to bolster support for antibiotic reduction technologies, accelerate breeding programs for disease-resistant duck breeds, facilitate alternative technologies, and advocate for multiple biosecurity and animal welfare measures to reduce antibiotic dependency in agriculture. Strengthening subsidy initiatives, considering the cost-benefit and risk management capacities of livestock farmers, is also crucial. Subsidy criteria should be tailored according to farm scale, with targeted implementation of subsidy policies. Encouraging farmers to manage farming risks through the purchase of livestock insurance could also be beneficial. Government support for such insurance purchases, along with efforts to optimize insurance claim standards and compensation plans by insurance companies, would enhance the incentivizing role of livestock insurance in the antibiotic reduction process. Furthermore, refining antibiotic reduction targets and regulatory measures by articulating specific reduction goals for different types of antibiotics and focusing on the applicability of regulatory measures across different contexts would foster better coordination among these measures. Strengthening collaboration between government and buyers is pivotal to fully harnessing the role of buyers in the antibiotic reduction journey. Finally, adopting tailored strategies based on the endowment factors of livestock farmers, such as implementing penalty and guidance measures for highly educated farmers and guidance measures for small-scale farmers, would help achieve effective antibiotic reduction outcomes.

This study has several limitations worth noting. First, it relies on survey data, where farmers' behaviors are influenced by their subjective perceptions of government and buyer regulations. Consequently, the data may not fully capture long-term changes, and responses may vary due to differences in farmers' perceptions and capacities. Second, farming conditions vary significantly across provinces, potentially limiting the generalizability of heterogeneity analysis results to all provinces. Future research should consider longitudinal surveys to capture dynamic changes more accurately and tailor policy decisions to the specific conditions of each province.

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