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# Contract governance to reduce antimicrobial overuse in hog farms in China

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ABSTRACT

Antimicrobial resistance caused by the overuse of antimicrobials by farmers is an essential health issue. Currently, signing contracts between farmers and cooperatives has become crucial for small farmers to integrate into the modern agricultural industry chain. Unlike vertical government governance, which aims to intervene in the overuse of antimicrobials by farmers through many mandatory or incentive measures, contract governance refers to the social governance model that clarifies rights and obligations between farmers and cooperatives to ensure the adequate performance of contracts, which is especially beneficial to regulate farmers' safe production behavior such as the standard use of antimicrobials. However, there is a research gap concerning the effectiveness of contract governance in inhibiting farmers' overuse of animal antimicrobials. This study applies propensity score matching and mediation analysis method to assess how contract governance affects the overuse of antimicrobials by hog farmers. The paper uses data from 498 hog farmers of China's Hebei, Henan, and Hubei provinces to explore the impact and underlying mechanisms of contract governance on antimicrobial overuse in agriculture. The results showed that contract governance was found to inhibit the overuse of antimicrobials, with the amount paid for antimicrobials reduced by 118 yuan/household. We found evidence that this effect is exerted through three mechanisms: cooperative supervision (*CS*), technical guidance (*TG*), and product premium perception (*PP*). The *CS*, *TG*, and *PP* mediation effects accounted for 19.94%, 27.90%, and 26.93% of the total impact, respectively. Therefore, policy implications of these results include strengthening the standard of contract signing procedures and the integrity of executing contracts, increasing the market premium for products that meet the antimicrobial residue standards, and enhancing farmers' knowledge and contracting ability.

## 1. Introduction

Animal antimicrobials have been playing a significant role in stabilizing the supply of livestock products, reducing animal morbidity and mortality, and promoting the growth of livestock [1]. In some developing regions and countries with poor feeding conditions & management and weak risk management ability, antimicrobials are essential input factors to improve farmers' family income & welfare and help them eliminate poverty [2,3]. China is the world's largest producer and consumer of animal antimicrobials. In 2020, China's consumption of animal antimicrobials was 32,776 tons, more than five times the international average [4]. Previous literature has confirmed that Chinese farmers use four times as many animal antimicrobials as American farmers to produce the same amount of meat [5]. More concerning is the overuse of animal antimicrobials, which increases antimicrobial residues, exacerbates antimicrobial resistance, and threatens health throughout the food and ecological chains [6–8]. Generally, farmers are regarded as the implementors and beneficiaries of animal antimicrobials, so curtailing the overuse of antimicrobials by farmers is of great significance for maintaining meat food safety, livestock production safety, and health.

Many previous studies on the overuse of antimicrobials by farmers mainly focused on three levels: 1) identifying the factors affecting the overuse of antimicrobials by farmers that mainly include individual characteristics, such as gender, age, and education level [9]; management characteristics, such as breeding experience, breeding scale,

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biosecurity measures, and participating organization [10–13]. Moreover, access to antimicrobials, veterinary services, government subsidies, government supervision, and skills training are also essential factors affecting farmers' decisions to overuse antimicrobials [14]. 2) The measuring of farmers' antimicrobial overuse has not been uniformly defined. Some scholars estimated the marginal productivity by employing a damage control model and hold that if the marginal productivity of antimicrobials used is close to 0, farmers overuse antimicrobials [15]. Other scholars argue that standard antimicrobial use mainly refers to farmers using antimicrobials at the recommended dosage prescribed by veterinarians (prescription antimicrobials) and the dosage specified in the package insert (over-the-counter drugs) [16]. Farmers are considered to have overused antimicrobials if the actual dose exceeds the standard dose. 3) Lastly, the intervention measures and existing studies mainly focused on government penalties and incentives. The mandatory measures mainly include compulsory immunization, inspection of antimicrobial residues, supervision of the withdrawal period, and inspection of antimicrobial use records [16,17]. The Chinese government does not directly subsidize farmers' standard use of antimicrobials. However, indirect subsidies for compulsory immunization, genetic improvement of livestock, and the safe disposal of dead livestock can reduce disease incidence in livestock and, consequently, reduce antimicrobials overuse [15].

Regrettably, government interventions have not yielded significant results. Asymmetric information exists between the government and the farmers regarding the use of antimicrobials, which hinders the effectiveness of government supervision [18]. Meanwhile, the subsidy amount for compulsory immunization and genetic improvement of livestock often falls short of covering the cost associated with epidemic prevention and control [19]. In particular, China's subsidy standards for compulsory immunization and genetic improvement for pigs are 1–3 yuan per head and 20–80 yuan per head, respectively. Furthermore, for subsidies ranging from 80 to 500 yuan per head for the harmless treatment of dead livestock, if the market price of slaughtered pigs is low, combined with the high cost of disease prevention and treatment, farmers may opt for passive disease management or choose not to treat it, aiming to increase their government subsidies. Consequently, the low subsidy standards and policies designed for rent-seeking weaken the effectiveness of incentive policy implementation. As a result, many countries have been exploring new initiatives to address the issue of antimicrobial overuse by farmers, aiming to compensate for the current lack of policy constraints or incentives.

Contract governance mainly refers to the signing of contracts between farmers and cooperatives, in which both parties agree that the cooperatives will provide unified standards or services, market price information, and product sales, and farmers will obey the organizational rules of the cooperatives [20,21]. These corporate rules mainly involve using all inputs, management models, and product quality certification. A large body of previous literature has confirmed the influence of contract governance on farmers' safe production behavior through security control, resource coordination, and risk management. First, by establishing unified production norms, cooperative rules can regulate the use of agricultural inputs, oversee the production process, and improve product quality [22,23]. Second, cooperative rules can coordinate the organization's internal resources to ease the information constraints of farmers' technology adoption, market price, and product sales, reduce market transaction costs, and improve agricultural income and family welfare [24–26]. Third, as an effective risk management tool, cooperative rules leverage the organization's information acquisition and resource advantages to predict risks related to natural disasters, technical aspects, and market conditions. Then, they implement robust risk management measures to reduce the uncertainty faced by farmers and curb opportunistic behavior [27,28].

The nature of this contract is a bilateral civil contract. Farmers have the freedom to choose whether to join cooperatives, and cooperatives have the option to select their potential members. Hence, both cooperatives and farmers have ample opportunities to sign contracts with each other. By 2022, there were over 40,000 hog cooperatives in China. The mechanism of interest correlation and liability for breach of contract is at the core of the effective operation of a contract. Specifically, on the one hand, the agreement stipulates that cooperatives provide pig-raising technology and breeding management services to farmers, including disease prevention, detection, and treatment. They also commit to buying back pigs at a protective price, which is not less than the lowest price, and apply for product quality certification to increase the product market premium. On the other hand, farmers must do farming following the safety production mode agreed upon in the contract. This includes adhering to standards for antimicrobials and enhancing biosafety system construction. Additionally, they must sell their pigs to cooperatives rather than market selection transactions. In cases of defaults by either party, compensation for the expected losses should be provided. Because antimicrobial residue testing is required for cooperatives to apply for pollution-free product quality certification, cooperatives often enforce the same rules for the standard use of antimicrobials among farmers. However, similar to a business contract, not all other contract terms are the same, and both parties can add or subtract some rules according to the actual production needs.

Based on the above content, the study contributes innovatively to the existing literature in the following ways: firstly, the study employs the propensity score matching (PSM) method to empirically analyze the effects of contract governance on the overuse of antimicrobials by using the data of China. Contract governance depends on the participation of farmers to promote the conclusion of contracts between the two sides, so there is a “self-selection” issue, which can be effectively solved by the PSM method. Secondly, mediation analysis is used to explore potential influence mechanisms (cooperative supervision, technical guidance, and product premium perception) by which contract governance inhibits the overuse of antimicrobials by farmers. Finally, the main conclusions and policy implications can provide important decision-making references for government departments to guide the sustainable implementation of the contract governance and promote the animal antimicrobial reduction action. The analytical framework used in the current study is shown in Fig. 1.

The rest of the paper is structured as follows: the second part relates to data, variables, and methods. The third section provides the model estimation results and influence mechanisms. The fourth part is associated with the discussion section, and the fifth part concludes the study with specific policy implications.

## 2. Materials and methods

### 2.1. Study sites, sampling, and participants

The data used in the current study is collected from a questionnaire survey on antimicrobials among hog farmers from Hebei, Henan, and Hubei provinces of China from July to September 2021. The research

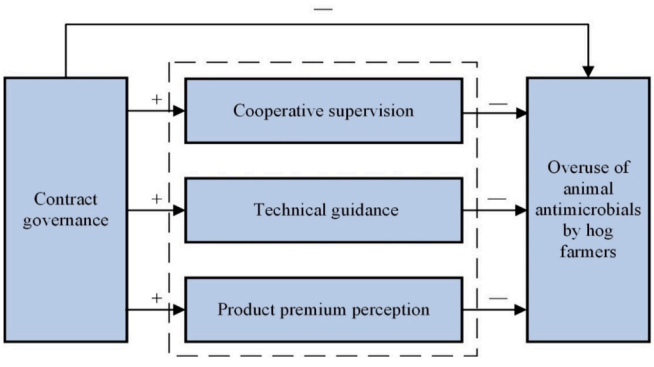


**Fig. 1.** The analytical framework used in the current study.

team distributed questionnaires in the form of face-to-face interviews. The research team, as interviewers, asked questions in the questionnaire and recorded the answers, and the hog farmers as answered. The questionnaire survey obtained consent from the interviewees, and the research team committed to protecting their personal privacy information. The research team consisted of 4 associate professors and six graduate students with professional expertise in public administration, agricultural economics, statistics, and econometrics. The reasons for choosing these three provinces as research areas were as follows: firstly, the density and scale of hogs bred in these provinces were extensive, and the hog industry had become a pillar industry for agricultural economic development. Secondly, these provinces had a high incidence of livestock infectious diseases, and the use of animal antimicrobials was also extensive. Thirdly, these provinces had implemented the reduction action of antimicrobials and adopted intervention measures against the overuse of antimicrobials by farmers. Finally, these provinces had a high degree of organization in pig breeding, a long livestock industry chain, and ample space for value appreciation. Accordingly, selecting these three provinces as research areas was typical and representative.

The research team obtained the list of counties where hogs were raised from provincial livestock departments and randomly selected five counties from each province for a questionnaire survey. The survey areas were Luanan, Tangxian, Pingshan, Funing, and Linzhang counties from Hebei Province; Jiyuan, Mengjin, Zhengyang, Ye county, and Zhaoling counties from Henan Province; Xishui, Zhushan, Huangmei, Jianli, and Xiangzhou counties from Hubei Province. Among them, Jiyuan county in Henan Province was the pre-research area of the research group. In the formal investigation, the research group randomly selected 2 to 4 sample towns from each county and randomly selected 12 to 16 hog farmers from each town for the questionnaire survey. The questionnaire mainly included farmers' endowments, family, and management characteristics, antimicrobial use, biosafety measures, policy tools & intervention measures, and joining cooperatives. Finally, 498 valid questionnaires were retained, and the sample sizes of Hebei, Henan, and Hubei were 168,182, and 148 households, accounting for 33.73%, 36.55%, and 29.72% of the total sample, respectively. Furthermore, due to the impact of environmental protection policies and the spread of African swine fever, many free-range farmers (whose annual output was less than 50 heads) quit hog farming in China. Hog breeding was mainly based on small and medium-sized farmers with yearly outputs between 50 and 500 heads.

### 2.2. Variable selection

#### 2.2.1. Explained variable

The explained variable was the overuse of antimicrobials by farmers. We defined the standard use of antimicrobials as the recommended dosage of veterinary prescriptions (prescription antimicrobials) and the dosage specified in the package insert (over-the-counter drugs). If the actual dose of the antimicrobials was much greater than the standard dose, the farmer overused the antimicrobials. The research team found that under the dual constraints of disease pressure and expected losses, it was almost impossible for farmers to use less than the standard dose. Thus, antimicrobial overdose is used = actual dose used minus standard dose used.

The previous literature has two main ways to measure the “dose” of antimicrobials. On the one hand, Echtermann et al. [29] directly used milliliters or grams to characterize the dose of antimicrobials used by farms. This measurement method was mainly applied to farms where single antimicrobials were used. However, there were significant differences in antimicrobials' types, preparations, concentrations, and packaging, and they couldn't be directly added in milliliters or grams. On the other hand, Zhao and Wen [30] and Liu et al. [31] measured the dose of antimicrobials according to the payment amount of antimicrobials purchased or invested to achieve the equivalent measurement of antimicrobials. We mainly used the amount paid for antimicrobials by hog farmers to measure the dose of antimicrobials, which was a continuous variable. Specifically, the study initially obtained the types of antimicrobials used by farmers based on the records of antimicrobials use. Secondly, we obtained the payment amount for antimicrobials through the specific items in the questionnaire regarding the expenditure on purchasing inputs. Finally, we performed a direct summing of the payment amounts for different types of antimicrobials to characterize the doses of antimicrobials. Furthermore, the price fluctuation range of antimicrobials in China was small, the use of antimicrobials by farmers was a family production decision, and the payment amount was measured to benefit our economic analysis.

#### 2.2.2. Core explanatory variable

The core explanatory variable was contract governance. The primary tool of contract governance was organizational rules. In the sample area, farmers joining cooperative organizations had become a new path for the orderly connection between small farmers and modern agriculture. Farmers and cooperative organizations had signed contracts for the standard use of antimicrobials, and the cooperative provided farmers with unified feed input, disease prevention & control, and technical guidance on antimicrobial use. The interest linkage between farmers and cooperatives drove the effective implementation of the contract. Therefore, if the farmer signed an agreement with the cooperative for the standard use of antimicrobials, the value was 1; If the farmer had not signed an agreement with the cooperative, the value was 0.

#### 2.2.3. Confounding variables

Confounding variables were upstream variables of the core explanatory variable or co-upstream variables of the core explanatory variable and the explained variable. By referring to Chen et al. [6] and David et al. [32]’s studies, this paper selected individual characteristics such as gender, age, and education level; family characteristics such as breeding time, breeding scale, breeding insurance, and Internet use; external conditions such as social network, peer effect, government publicity, government technical training, and government supervision as confounding variables.

### 2.3. Propensity Score Matching (PSM) method

We employed the PSM method to analyze the influence of contract governance on farmers' overuse of animal antimicrobials. The advantages of the PSM model were as follows. First, it was voluntary and self-selected for farmers to sign contracts with cooperatives. The PSM model could correct the biased estimations caused by sample self-selection issue [33]. Secondly, due to the difference in capital endowment between the experimental group (farmers who signed contracts) and the control group (farmers who did not sign contracts), the effect of contract governance on farmers' overuse of antimicrobials could not be calculated by simple statistical comparison. We essentially wanted to analyze whether the farmers in the experimental group used fewer doses of antimicrobials than if these farmers had not signed the contract. Assuming that farmers who had signed contracts did not have agreements with cooperatives, the data on their antimicrobial overuse was unavailable, which was a “missing data” problem. Finally, Rosenbaum and Rubin [34] proposed a PSM method, which could build a counterfactual causal analysis framework. The idea of PSM was to match the samples of the experimental group and the control group according to propensity score so that the main characteristics of the experimental group and the control group were as similar as possible, and then the control group was used to simulate the state of the experimental group without signing a contract (counterfactual), and finally the difference in antimicrobials used between the contract farmers and their non-contract was compared.

Firstly, the Logit model was used to estimate the propensity score value, which was the conditional fitting probability of whether farmers signed contracts. The formula was as follows:

$$PSi = Pr(C = 1|Z_i) = E(C = 0|Z_i) \quad (1)$$

where$C = 1$signified farmers had signed the contract,$C = 0$signified farmers without signing the contract,$i$indicated the$i - th$farmers,$Z_i$represented the control variables,$E$was the expected value of non-contracted farmers under different control conditions.

Secondly, nuclear matching, radius matching, and nearest neighbor matching (K = 6) methods were selected to match the samples of the experimental group (farmers who signed contracts) and the control group (farmers who did not sign contracts).

Thirdly, the difference in the amount paid for the overuse of antimicrobials by contracted and non-contracted farmers was calculated; that was, the experimental group's average treatment effect (*ATT*) was used to measure the effect of contract governance on the overuse of antimicrobials by farmers. The expression of *ATT* was as follows:

$$ATT = E(Y_1|C = 1)\text{-}E(Y_0|C = 1) = E(Y_1\text{-}Y_0|C = 1) \quad (2)$$

Where$Y_1$was the payment amount for antimicrobial overuse of experimental group samples, $Y_0$was the payment amount for antimicrobial overuse if farmers who had signed contracts did not sign contracts with cooperatives.$E(Y_1|C = 1)$could be directly observed, but$E(Y_0|C = 1)$couldn't be directly observed.

Finally, the common support and balance test was used further to verify the robustness of model estimation results. A common support test was used to determine whether the experimental and control groups had a common support area and a partial overlap in the value range of propensity score. Meanwhile, the purpose of the balance test was to determine the quality of the match by comparing the significant differences in explanatory variables between the experimental and control groups.

### 2.4. Mediation analysis method

The mediation analysis mainly discussed the influence paths of the core explanatory variable on the explained variable, the core explanatory variable on the mediating variable, and the core explanatory variable & the mediation variable on the explained variable. This paper further used the mediation analysis to verify the influence mechanism concerning contract governance inhibiting the overuse of antimicrobials by farmers. The mediation variables selected mainly include "cooperative supervision"(*CS*), "technical guidance"(*TG*), and "product premium perception"(*PP*). The questions in the questionnaire were as follows: "the intensity of supervision of the standard use of antimicrobials by cooperatives (very weak =1 – very strong =5)", "the number of times that cooperatives carried out technical guidance on the standard use of antimicrobials (times)," and "the possibility of increasing the market premium through product quality certification by cooperatives (very low probability =1 – very high probability =5)". Concerning Wen and Ye's [35] study, this paper adopted the linear regression method for estimated the mediation effect, and the equation was constructed was as follows.

$$Y_i = \alpha_0 + \alpha_1 CG_i + \alpha_2 Control_i + \mu_1 \quad (3)$$

$$Mediator_i = \omega_0 + \omega_1 CG_i + \omega_2 Control_i + \mu_2 \quad (4)$$

$$Y_i = \alpha_0' + \alpha_1' CG_i + \alpha_2' Mediator_i + \alpha_3' Control_i + \mu_3 \quad (5)$$

Where the explained variable$Y_i$was the overuse of antimicrobials by farmers, the core variable $CG_i$was contract governance, and the mediation variables $Mediator_i$were the *CS*, *TG*, and *PP*. $\alpha_0$、$\omega_0$、$\alpha_0'$were constant terms, and $\mu_i$indicated random error terms. The specific mediating effect test procedure was as follows: (1) when $\alpha_1$was significant, the total effect was verified. Further, if the direction of indirect effect ($\omega_1 \times \alpha_2'$) and direct effect $\alpha_1'$was same, showing that there was a general mediating effect; if the direction of indirect effect ($\omega_1 \times \alpha_2'$) and direct effect $\alpha_1'$was opposite, indicating that the mediating effect was masked and the total effect was overestimated or underestimated. (2) Take the same direction for example, if both $\omega_1$and $\alpha_2'$were significant, the significance of $\alpha_1'$would be tested. If $\alpha_1'$was significant, a partial mediating effect would exist and the mediating effect was $\omega_1 \times \alpha_2'$; if $\alpha_1'$was not significant, there was a full mediating effect. (3) The *Sobel* test was performed if either$\omega_1$and $\alpha_2'$was insignificant. If the *Sobel* test results were significant, there was a mediating effect, and the mediating effect was $\omega_1 \times \alpha_2'$. The *Sobel* test results had a critical value of about 0.97 at the 5% significance level [36].

Mediator-outcome confounders (control variables) were often different than exposure-outcome confounders. According to VanderWeele et al. [37]'s principle of selection of confounding variables, we screened the confounding variables$Control_i$ in Eqs. (3)–(5). Specifically, firstly, Eq. (3) was to analyze the total effect of the core explanatory variable on the explained variable, and this part did not include the mediating variables as confounding factors and the confounding factors included the gender, age, and education level, breeding time, breeding scale, breeding insurance, and Internet use, social network, peer effect, government publicity, government technical training, and government supervision. Secondly, Eq. (4) analyzed the influence of the core explanatory variables on the mediating variables, and there was no reason to reject the hypothesis that these confounding variables were upstream variables of the core explanatory variable or co-upstream variables of the core explanatory variable & the mediation variable. Therefore, the confounding variables was the same as Eq. (3). Finally, Eq. (5) analyzed the influence of core explanatory variables and mediating variables on the explained variables. Government supervision, technical training, and publicity often relied on the direct implementation of cooperative organizations. The two sides present a principal-agent relationship, and the behavior of the government was easily confused with that of the cooperative. Thus, when analyzing the mediating effect of the *CS, TG, and PP*, respectively, the government supervision, government technical training, and government publicity was excluded in turn from the confounding variables. The removed confounding variables were parallel to the mediating variables, which did not conform to the basic principle of upstream variables.

## 3. Results

### 3.1. Descriptive analysis of variables

About 550 questionnaires were sent out; 52 samples, such as missing data and obvious falsification, were excluded, and 498 valid questionnaires were retained for empirical analysis. According to Table 1, it could be found that the average payment of farmers overusing antimicrobials was 4.044 hundred yuan/household. About 62.05% of farmers signed contracts with cooperatives and accepted contractual terms for the standard use of antimicrobials. The farmers surveyed were mainly male, with an average age of 56.73 years, less than six years of education, and nearly nine years of pig-raising experience. The breeding scale with less than 200 head accounted for 66.77%. Only 56.51% of farmers had purchased hog disease insurance, and less than 50% obtained information on the standard use of antimicrobials through the Internet. Farmers often shared knowledge of antimicrobial use with five other farmers, and their antimicrobial use behavior was also influenced by similar behavior of other farmers. Furthermore, the government had strengthened policy interventions for the standard use of antimicrobials through government publicity, technical training, and supervision. In particular, the average number of times the government publicized the standard use of antimicrobials was 3.031, the average number of times the government conducted technical training was 1.605, and the intensity of government supervision was 2.643.

**Table 1**
Descriptive statistical analysis of variables.

| Variables | Descriptions | Proportion (%) | Min | Max | Mean (S. D.) |
|---|---|---|---|---|---|
| Antimicrobials overused | Antimicrobial overdose used = actual dose used-standard dose used (Hundred yuan) | | 0 | 5.756 | 4.044 (1.654) |
| Contract governance* | Had you signed a contract with the cooperative for the standard use of antimicrobials? (Yes =1; no =0) | Yes (62.05%) No (37.95%) | 0 | 1 | |
| Gender* | Male =1; female =0 | Male (75.20%) Female (24.80%) | 0 | 1 | |
| Age | Actual age (Year) | | 27 | 67 | 56.730 (11.205) |
| Educational level | Time for education (Year) | | 6 | 16 | 5.850 (3.616) |
| Breeding time | Time spent raising hogs (Year) | | 2 | 28 | 8.617 (2.012) |
| Breeding scales* | Number of hogs raised in 2020 (1–100 head = 1, 101–200 head =2, 201–300 head =3, 301–400 head =4, and more than 400 head =5) | 1–100 head (36.51%) 101–200 head (30.26%) 201–300 head (18.75%) 301–400 head (8.16%) More than 400 head (6.32%) | 1 | 5 | |
| Breeding insurance* | Did you buy hogs' disease insurance? (Yes =1; no =0) | Yes (56.51%) No (43.49%) | 0 | 1 | |
| Internet use* | Was information about standard antimicrobial use available via mobile phone or computer? (Yes =1; no =0) | Yes (44.31%) No (55.69%) | 0 | 1 | |
| Social network | The number of other farmers you interacted with regularly (people) | | 3 | 12 | 4.898 (1.996) |
| Peer effect | Did other farmers influence your antimicrobial use? (No effect at all = 1– significant effect = 5) | | 0 | 1 | 3.354 (1.049) |
| Government publicity | The number of times the government publicized the standard use of antimicrobials (Times) | | 1 | 6 | 3.031 (0.602) |
| Government technical training | The number of times the government conducted technical training on the standard use of antimicrobials (Times) | | 1 | 4 | 1.605 (0.701) |
| Government supervision | The intensity of government regulation on standard use of antimicrobials (Very light = 1– very strict = 5) | | 1 | 5 | 2.643 (1.292) |

Note: *represented the proportion of the categorical variable to the total sample rather than the mean (S.D.).

### 3.2. Statistical inference of differences between signing and non-signing contract samples

In the sample, 309 farmers signed contracts, and 189 farmers did not sign contracts, accounting for 62.05% and 37.95% of the total samples, respectively. The parameter *t*-test results in Table 2 showed that the difference in the amount paid for antimicrobial overuse between farmers signing and non-signing contracts held negative significance (*alpha* = 0.05). Contractual farmers used less antibacterials than non-contractual farmers (*diff.* = −0.971). Meanwhile, the results showed significant differences in breeding insurance between the contract and non-contract groups (*alpha* = 0.10). Compared with farmers who did not sign contracts, farmers who signed contracts had a higher probability of buying breeding insurance (*diff.* = 0.078). Moreover, there were significant differences in educational level, breeding scale, and government supervision between signing and non-signing contract groups (*alpha* = 0.05). Compared with non-contracted farmers, contracted farmers had better educational levels (*diff.* = 0.665) and larger breeding scales (*diff.* = 0.240), as well as accepted higher government supervision intensity (*diff.* = 0.224). Furthermore, there were significant differences in Internet use, social networks, and government technical training between the contract and non-contract groups (*alpha* = 0.01). Compared with non-contracted farmers, contracted farmers were more likely to obtain standard antimicrobial use information through the Internet

**Table 2**
Statistical inference of variables.

| Variables | The mean of the variables in the signing contract samples (B) | The mean of the variables in the non-signing contract samples (C) | Difference (B—C) | *T*–value |
|---|---|---|---|---|
| Antimicrobials overused | 3.558 | 4.529 | −0.971** | −2.015 |
| Contract governance | 1 | 0 | – | – |
| Gender | 0.733 | 0.770 | −0.037 | −1.572 |
| Age | 57.469 | 55.990 | 1.479 | 1.306 |
| Educational level | 6.182 | 5.517 | 0.665** | 2.290 |
| Breeding time | 8.909 | 8.325 | 0.584 | 1.065 |
| Breeding scales | 2.144 | 1.904 | 0.240** | 2.172 |
| Breeding insurance | 0.604 | 0.526 | 0.078* | 1.805 |
| Internet use | 0.513 | 0.373 | 0.140*** | 3.046 |
| Social network | 5.393 | 4.402 | 0.991*** | 2.954 |
| Peer effect | 3.377 | 3.330 | 0.047 | 1.402 |
| Government publicity | 2.994 | 3.067 | −0.073 | −1.291 |
| Government technical training | 1.962 | 1.247 | 0.715*** | 2.657 |
| Government supervision | 2.755 | 2.531 | 0.224** | 2.086 |
| Sample size | 309 | 189 | – | – |

Note: The mean of the variables was reported, and the difference was tested using a parameter *T*-test. *, **, and *** were significant at the 10%, 5%, and 1% levels, respectively.

(*diff*. = 0.140), had higher social network strength (*diff*. = 0.991), and received more government technical training (*diff*. = 0.715).

### 3.3. The effect of contract governance on the overuse of antimicrobials by farmers

The Logit model first was used to estimate the propensity score of farmers' contract decisions to create the matching environment with the highest similarity and ensure the matching quality. The results in Table A1 (in supplementary file) showed that age, education level, breeding time, breeding insurance, Internet use, and government supervision positively and significantly influenced farmers' decision to sign contracts. Besides, the model estimation results were biased because there might be multicollinearity among all explanatory variables. Hence, this paper used the variance inflation factor (VIF) method to test the multicollinearity. Contract governance was used as the explained variable, and other variables were used as explanatory variables for regression. The test results reported in Table A2 (in supplementary file) that the minimum value of VIF was 1.03, the maximum was 1.09, and the mean was 1.06. All VIF values were less than the boundary value 10, indicating no multicollinearity issue.

We further used three matching methods to analyze the net effect of contract governance on farmers' overuse of antimicrobials. In the sample, 366 farmers overused antimicrobials, and 132 used standard antimicrobials. Table 3 showed that although the results of the three matching methods were slightly different, treatment effects were all negative, and *ATT* (average treatment effect) all passed the significance test (*alpha* = 0.05). The estimated results of the counterfactual hypothesis showed that if the farmers who signed the contract did not sign it, the amount paid for antimicrobials would reach 4.711–4.859 hundred yuan/household. After the farmer signed the contract, the payment amount for antimicrobials would be reduced to 3.587 hundred yuan/per household. The contract governance decreased farmers' payment amount for the overuse of antimicrobials by 1.124–1.272 hundred yuan/per household. Furthermore, the mean value of the *ATT* was −1.180. Accordingly, contract governance had a significant inhibitory effect on the overuse of antimicrobials by farmers, and the amount paid for antimicrobials would be reduced by 1.180 hundred yuan/household.

### 3.4. Checking the quality of the sample match

#### 3.4.1. Common support test

The propensity score could be calculated according to the estimation results of farmers' contract decisions in formula (1). Then, the standard support domain of the experimental and control groups could be analyzed. If the common support domain were too narrow, the samples outside the common support domain would not be effectively matched, which would also cause more sample loss. The statistical results showed that the propensity score intervals of contract farmers and non-contract farmers are [0.12, 0.87] and [0.13, 0.85], respectively, and the interval of the common support domain was [0,13, 0.85]. Meanwhile, the study plotted the probability density of propensity scores between the experimental and control groups before and after the sample matched. According to Fig. 2, after the sample matched, the kernel density function of the propensity score of the experimental and control groups was relatively close, and the sample-matched effect was good.

According to the three matching methods, the sample loss was also different. Fig. 3 reported the results of maximum sample loss. It could be found that the experimental group lost four samples, the control group lost three samples, and 491 samples matched. Meanwhile, fewer samples were lost, and the matched effect between the treatment and the control groups was good.

**Table 3**
The net effect of contract governance on the overuse of antimicrobials by farmers based on different matching methods.

| Matching method | Treatment group | Control group | *ATT* | Standard error |
|---|---|---|---|---|
| Nuclear matching | 3.587 | 4.732 | −1.145** | 0.474 |
| Radius matching (*R* = 0.05) | 3.587 | 4.711 | −1.124** | 0.474 |
| Nearest neighbor matching (K = 6) | 3.587 | 4.859 | −1.272** | 0.503 |
| The mean value of the *ATT* | | | −1.180 | |

Note: ** represented significance at the 5% level.

#### 3.4.2. Balance test

Table 4 reported the balance test results of explanatory variables before and after the samples were matched. After the sample was matched, Pseudo-$R^2$ decreased significantly, from 0.055 before the match to 0.003–0.008 after the match. The LR statistics also decreased significantly, from 38.80 before the match to 2.38–6.78 after the match. Furthermore, the mean deviation decreased significantly, from 11.9 before the match to 2.3–4.2 after the match, and the median deviation was from 12.7 before the match to 1.3–2.5 after the match. It could be seen that the total sample bias was significantly reduced after the sample was matched, and the experimental and control samples had similar characteristics; that was, the balance test was passed.

### 3.5. Analysis of the influence mechanism of contract governance

This paper further tested the mediation effect of *CS*, *TG*, and *PP* concerning contract governance inhibiting farmers' overuse of antimicrobials. The linear hierarchical regression results showed that, first, in Table 5 (1)–(3), contract governance had a significant negative effect on the overuse of antimicrobials by farmers. Meanwhile, contract governance positively influenced the *CS*. Meanwhile, both contract governance and *CS* exerted a significant negative impact on the overuse of antimicrobials by farmers, indicating that the partial mediation effect of *CS* was −0.268 (0.670 × −0.400), and the proportion of the mediation effect in the total effect was 0.1994 (−0.268/−1.344). It showed that 19.94% of the inhibition effect of contract governance on the overuse of antimicrobials by farmers was obtained through the *CS*. Second, in Table 5 (4)–(6), the negative effect of contract governance on the overuse of antimicrobials by farmers was significant. Contract governance positively and significantly impacted the *TG*. Both contract governance and *TG* had a significant negative influence on the overuse of antimicrobials by farmers, indicating that the partial mediation effect of the *TG* was −0.375 (0.626 × −0.599), and the proportion of the mediation effect in the total effect was 0.2790 (−0.375/−1.344). It reported that 27.90% of the inhibition effect of contract governance on the overuse of antimicrobials by farmers was realized through the *TG*. Third, in Table 5 (7)–(9), contract governance negatively and significantly influenced the overuse of antimicrobials by farmers. Meanwhile, contract governance played a positive role in promoting *PP*. Both contract governance and *PP* had significant negative effects on the overuse of antimicrobials by farmers, indicating that the partial mediation effect of market premium perception was −0.362 (0.399 × −0.907). The proportion of the mediation effect in the total effect was 0.2693 (−0.362/−1.344), indicating that 26.93% of the inhibitory effect of contract governance on the overuse of antimicrobials by farmers was obtained through the *PP*. Thus, the *CS*, *TG*, and *PP* mediation effects accounted for 19.94%, 27.90%, and 26.93% of the total effect, respectively. The *TG* has the most substantial inhibitory effect, followed by the *PP* and *CS*.

## 4. Discussion

Under the African swine fever epidemic and other bacterial diseases, the overuse of antimicrobials by farmers in developing countries is a serious health issue. The use of animal antimicrobials is a double-edged sword. On the one hand, it can improve biosecurity and reduce disease

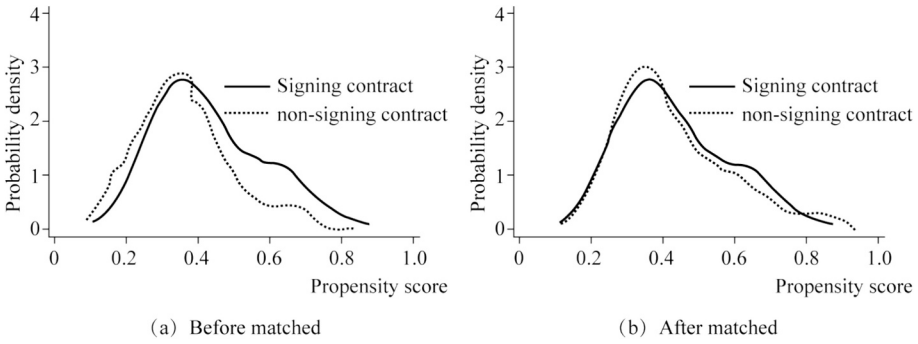


**Fig. 2.** Probability density of propensity score.

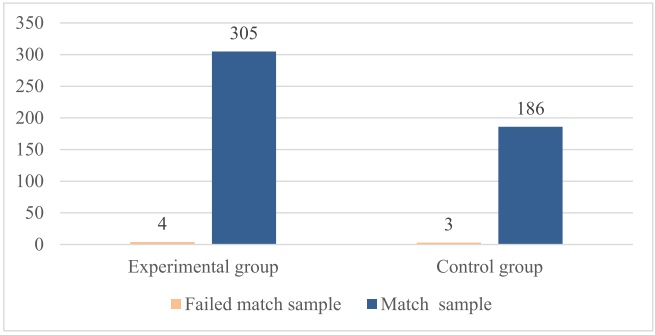


**Fig. 3.** Evaluation of sample loss.

**Table 4**
The results of the balance test.

| Matching method | Pseudo-$R^2$ | LR statistic | Mean deviation | Median deviation | B-value | R-value |
|---|---|---|---|---|---|---|
| Before matching | 0.055 | 38.80 | 11.9 | 12.7 | 56.3* | 0.95 |
| Nuclear matching | 0.003 | 2.41 | 2.4 | 1.3 | 12.4 | 1.50 |
| radius matching (R = 0.05) | 0.003 | 2.38 | 2.3 | 1.6 | 12.3 | 1.55 |
| Nearest neighbor matching (K = 6) | 0.008 | 6.78 | 4.2 | 2.5 | 20.8 | 1.41 |

Note: * represented significance at the 10% level.

outbreak risks [38,39], promote livestock growth, and improve production efficiency [40]. On the other hand, the negative externalities of overuse of antimicrobials are apparent, such as antimicrobial residues, bacterial resistance, and the spread of ARGs [41–43]. Furthermore, the damage of antimicrobial resistance has the characteristics of intertemporal and cumulative, which makes global governance of antimicrobials more difficult. Many countries have adopted mandatory and incentive government intervention policies to achieve incentive compatibility between reducing antimicrobial overuse and increasing livestock production. However, information on antimicrobial use is highly secretive and one-sided. Previous interventions cannot address the information asymmetry on antimicrobial use between the government and farmers [44]. From the perspective of behavioral economics and agricultural economics, the intervention of farmers' behavior should be included in the relationship network [45]. Organization participation is essential for small farmers to integrate into the modern agricultural industry chain and transform their production mode [46–48]. With many small and medium-sized farms in China signing contracts with cooperative organizations, cooperative rules on the standard use of antimicrobials are beneficial to achieve effective contract governance through reciprocal exchange, self-commitment, and self-compliance.

Meanwhile, contract governance may change the relationship network structure, induce farmers to actively share information on antimicrobial use, and significantly reduce information asymmetry. The main innovation of this paper is that it theoretically expands the connotation and application boundary of farmer behavior theory and incorporates contract governance into social governance rules, which is conducive to building a diversified social governance system. Meanwhile, the study explored the influence mechanism of contract governance on the overuse of antimicrobials by farmers. In practice, the study empirically evaluated the effectiveness of contract governance in addressing the overuse of antimicrobials by farmers, providing a beneficial reference for antimicrobials reduction actions in other developing countries.

The current study confirms the effectiveness of contract governance in reducing antimicrobial overuse by farmers. Consistent with Mao et al. [21], the finding demonstrates the effectiveness of contract governance in reducing the use of agricultural inputs. Meanwhile, Liu et al. [49] also hold that written agreements for vertical collaboration can help farmers to opt for the standard use of antimicrobials. Similar studies, such as Wu and Qiao [50] and Wang et al. [25], also argued that joining cooperative organizations is beneficial to drive farmers to enforce the withdrawal period of antibacterials strictly. Furthermore, some scholars also found that the non-integrity of contracts and the low cost of default frustrate the sustainability of contract governance [51]. The results of the above research can be interpreted from the following aspects. Firstly, unlike official government regulation, the contract is a kind of self-claimed and mild supervision, and this supervision enhances contractual obligations or responsibilities [52]. Secondly, the main tools of contract governance are the supply of technical services and accountability for breach of contract. Benefit linkage, rule constraint, and risk sharing under contract governance are good for helping farmers implement safe production behaviors and reduce the overuse of antimicrobials [53,54]. Finally, contract governance introduces the market incentive mechanism. For example, cooperative organizations improve the market competitiveness of farmers' product quality, product prices, and family income by obtaining product quality certification [55,56]. Of course, some potential risks in contract governance cannot be ignored. For example, cooperatives and farmers are sometimes unequal, and smallholders still face passive contracts in areas with fewer contractual partners. In addition, smallholder farmers have limited knowledge and skills in understanding contract terms, affecting the sustainable implementation of contracts.

The study further explored the influence mechanism of contract governance in reducing the overuse of antimicrobials by farmers. The results confirm that the *CS*, *TG*, and *PP* play an essential role in inhibiting the overuse of antimicrobials by farmers, and the proportion of their mediation effect in the total effect was in the order of *TG* (27.90%) > *PP* (26.93%) > *CS* (19.94%). Firstly, consistent with Doidge et al. [57]

**Table 5**
Analysis of the influence mechanism of contract governance.

| Variables | cooperative supervision (*CS*) mechanism | | | technical guidance (*TG*) mechanism | | | product premium perception (*PP*) mechanism | | |
|---|---|---|---|---|---|---|---|---|---|
| | Antimicrobials overused | *CS* | Antimicrobials overused | Antimicrobials overused | *TG* | Antimicrobials overused | Antimicrobials overused | *PP* | Antimicrobials overused |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| Contract governance | −1.344** (0.611) | 0.670*** (0.113) | −1.075*** (0.364) | −1.344** (0.611) | 0.626*** (0.113) | −0.953*** (0.360) | −1.344** (0.611) | 0.399*** (0.131) | −0.982** (0.338) |
| *CS* | | | −0.400*** (0.138) | | | | | | |
| *CTG* | | | | | | −0.599*** (0.137) | | | |
| *PPP* | | | | | | | | | −0.907*** (0.113) |
| $R^2$ | 0.305 | 0.242 | 0.402 | 0.305 | 0.111 | 0.415 | 0.305 | 0.067 | 0.461 |
| Prob>F | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Mediation effect | −0.268 | | | −0.375 | | | −0.362 | | |
| Mediation effect/total effect | 0.1994 | | | 0.2790 | | | 0.2693 | | |

Note: ** and *** represented significance at the 1% level, respectively; the standard error is in brackets.

and Bradford et al. [58], the current study verifies that technical constraints are an essential incentive for farmers to overuse antimicrobials. Cooperative organizations are not only the direct beneficiaries of agricultural technology extension by the livestock sector but also have their technical personnel and play a leading role in the vertical extension and diffusion of agricultural technology [59–61]. As Liu et al. [31] argue, skills training carried out by cooperatives can significantly reduce the dosage of antibacterials used by farmers. Secondly, consistent with Yu and Wang [62]'s research, it is also realized that contract governance supplements the lack of government supervision through contract supervision. According to the contract terms, contract governance can formulate uniform production safety standards, clear the adverse damage of violating the standard use of antimicrobials, avoid the risk of farmers' opportunism, and restrict farmers from actively reducing the overuse of antimicrobials [16,17,63]. Thirdly, through large-scale and safe agricultural production, cooperatives can ensure that the products produced by their members meet the standards of antimicrobial residues and then obtain the product quality certification and the market premium effect [64]. Previous studies also confirmed the promotion effect of product premium perception on farmers' production safety and technical efficiency [65]. Hence, contract governance drives farmers to reduce the overuse of antimicrobials by improving the perception level of farmers' product premiums.

Besides, many key driving factors influencing farmers' decision to sign contracts are identified. Signing contracts is an essential tool for farmers to manage agricultural risks. Consistent with the studies of Joffre et al. [66], Hasibuan et al. [67], and Nguyen-Trung et al. [68], the current study also confirms the positive role of age and education level in promoting farmers' risk management behaviors. The older farmers are, the weaker their ability to bear risks, and the more inclined they are to join cooperatives. The higher the education level, the more thoroughly the understanding of contract agriculture, and the higher the initiative to sign contracts. Of course, farmers will not let the risk occur or transfer after joining the cooperative; they will also buy breeding insurance to deal with disease and market risks [69,70]. Moreover, traditional smallholder agriculture is mainly empirical agriculture, and technology or information constraint is the bottleneck factor of smallholder management transformation [71,72]. Consistent with many previous studies, breeding time reflects farming experience that can guide farmers to achieve production transformation through cooperation with cooperatives [73,74]. Furthermore, using the Internet has changed farmers' access to information, improved their information literacy and knowledge accumulation, and made it easier to accept modern contract governance rules [16,75]. The production behavior of farmers is the result of both internal and external factors. Furthermore, from the perspective of external factors, the government's supervision of antimicrobials is also an essential motivation for farmers to maintain safe production and engage in modern breeding by joining cooperatives.

There are still certain limitations in the present study that need further elaboration. Firstly, our empirical results are based on statistical and metrological analysis of 498 hog farmer surveys. However, statistical significance reflects sample size more than anything else, and shouldn't really be used to make modeling decisions. Statistical significance is highly correlated with sample size, and the model decision should not rely solely on numbers or significance but should also consider its gap with the real world. Secondly, previous studies have confirmed the regional heterogeneity of animal antimicrobials used in China [76]. However, this study only conducted a questionnaire survey on three contiguous provinces. The heterogeneity of contract governance effects has not been analyzed. Thirdly, the mediation mechanism of contract governance is multi-dimensional. However, the present study only conducted empirical analysis from the *CS*, *TG*, and *PP*; other possible mediation variables were not considered. Finally, the study only discussed how contract governance could inhibit the overuse of antimicrobials by farmers from the perspectives of agricultural economics and behavioral economics and then designed the standard of antimicrobials & the measurement standard of overuse. Global management of animal antimicrobials requires multi-sectoral, multi-disciplinary, and multi-subject joint research and intervention. Of course, these deficiencies provide a new perspective and direction for the research group's future research.

### 4.1. Conclusion and policy implications

#### 4.1.1. Main conclusion

Reducing the residue and resistance of animal antimicrobials effectively and maintaining global health are essential issues that must be solved urgently. The incentive compatibility of reducing antimicrobial overuse and maintaining livestock production safety poses a vital challenge to the design of public policy and social governance systems. As the world's largest hog breeding country, focusing on the real problem of overuse of antimicrobials by farmers, the present study empirically analyzes the effectiveness of contract governance in solving this problem. This paper employs the PSM method and mediation analysis to empirically examine the influence and mechanism of contract governance on the overuse of antimicrobials by farmers, using the survey data of 498 hog farmers from Hebei, Henan, and Hubei provinces of China. The main conclusions are as follows: firstly, contract governance has a significant

inhibitory influence on the overuse of antimicrobials by farmers, and the amount paid for antimicrobials will be reduced by 1.180 hundred yuan/household. Secondly, contract governance inhibits the overuse of antimicrobials by farmers through the *CS*, *TG*, and *PP*. The *CS*, *TG*, and *PP* mediation effects accounted for 19.94%, 27.90%, and 26.93% of the total effect, respectively. Therefore, the *TG* has the most substantial inhibitory effect, followed by the *PP* and *CS*. Finally, age, breeding time, insurance, education level, government supervision, and Internet use positively and significantly influence farmers' decisions to sign cooperative contracts.

### 4.2. Policy implications

The following policy implications are drawn for reducing antimicrobial overuse, residue & resistance. Firstly, the government should strengthen the guidance on the contract between farmers and cooperatives, improve the standard of signing contract procedures and the integrity of executing contracts, strengthen the accountability for breach of contract, and constantly improve the effectiveness of contract governance. Meanwhile, the government should explore the synergistic effect of government supervision, market incentives, and contract governance and improve the diversified social rules system of animal antimicrobial management. Secondly, the government should establish a sound product quality certification system, give green or pollution-free certification to products that meet the antibacterial residue standards, improve the market competitiveness and premium effect of meat products, and encourage farmers to reduce antimicrobial overuse actively. Finally, the government should strengthen the knowledge training for farmers on contract terms, performance, and breach of contract to improve farmers' willingness and ability to sign contracts. In addition, the study also called for comprehensive global cooperation on the experience, techniques, and intervention models in the irregular use of animal antimicrobials.

## Ethics approval and consent to participate

The questionnaire survey for this study was reviewed and approved by the Xi'an University of Architecture and Technology Ethics Committee [Approval No. XAUAT – 21086]. Following the questionnaire survey, the School of Public Administration at Xi'an University of Architecture and Technology conducted a retrospective ethical inspection regarding recruitment, informed consent, and data management, among other factors [Approval No. 2022–001]. The recruitment of participants was conducted based on voluntary and informed consent, ensuring the protection of participants' rights and privacy. The research content does not present any conflicts of interest or violate moral, ethical, or legal prohibitions. Additionally, participants were provided with information about the aim and procedures of the study, given time to ask questions, and agreed to participate by signing a consent form.

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## CRediT authorship contribution statement

**Ruishi Si:** Writing – original draft, Formal analysis, Data curation, Conceptualization. **Xin Liu:** Software, Methodology, Formal analysis, Data curation. **Xueqian Zhang:** Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Yi Chen:** Software, Methodology, Investigation. **Wen Xiang:** Writing – review & editing, Software, Funding acquisition. **Mingyue Liu:** Writing – review & editing, Funding acquisition. **Yongfeng Tan:** Conceptualization, Data curation, Formal analysis, Supervision. **Guotao Yang:** Funding acquisition, Investigation, Methodology, Supervision.

## Declaration of competing interest

The authors declare that they have no competing interests.

## Data availability

The data that has been used is confidential.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.onehlt.2024.100859.

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