

Risk Awareness or Regulatory Burden? Trust, One Health Responsibility, and Antimicrobial-Use Compliance in Chinese Food-Animal Production

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Research Article

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Abstract

Background: Antimicrobial resistance (AMR) is a One Health governance problem linking human medicine, food-animal production, food safety, and environmental protection. This study explains why producers who recognize AMR and food-safety risks may still continue practices that conflict with prudent antimicrobial stewardship.

Methods: Using a sequential mixed-methods design, this study examines antimicrobial-use compliance among 3,647 Chinese food-animal producers surveyed across eight provinces between March and September 2025, with an embedded $2 \times 2 \times 2$ vignette experiment and a behavioral-validation subsample of 412 producers.

Results: AMR risk awareness was positively associated with One Health responsibility ($\beta = 0.42$, $SE = 0.03$, $p < 0.001$) and compliance ($\beta = 0.16$, $SE = 0.04$, $p < 0.001$), while One Health responsibility was strongly associated with compliance ($\beta = 0.48$, $SE = 0.03$, $p < 0.001$). The indirect association through responsibility was substantial ($\beta = 0.20$, 95% CI [0.16, 0.24]), but the conversion of responsibility into compliance depended on institutional conditions: regulatory trust and veterinary trust strengthened the pathway, whereas administrative burden weakened it. The vignette experiment showed that One Health framing, support-oriented regulation, and veterinary support increased stated compliance intention. Record validation indicated moderate agreement with self-reports and 12-18% over-reporting for record keeping and withdrawal-period compliance.

Conclusion: The study contributes to food-safety governance, One Health implementation, and administrative-burden theory by showing that risk awareness becomes stewardship behavior only when responsibility is supported by trusted institutions, credible veterinary advice, and low-burden compliance pathways.

1. Introduction

Antimicrobial resistance (AMR) has become one of the most consequential governance challenges at the intersection of public health, food systems, and environmental protection. Global estimates identify bacterial AMR as a major contributor to mortality and health-system burden, while international agencies increasingly emphasize that resistant organisms and antimicrobial residues can circulate across humans, animals, food chains, waste streams, and ecosystems (Antimicrobial Resistance Collaborators, 2022; WHO, 2015, 2023). The One Health approach therefore treats AMR not as a problem confined to clinical medicine but as a shared challenge of human health, animal health, plant health, food safety, and environmental stewardship (FAO, UNEP, WHO, & WOA, 2022; Rousham et al., 2018). Food-animal production occupies a particularly important position in this system because antimicrobials are used to prevent and treat disease, protect animal welfare, stabilize productivity, and reduce economic loss. At the same time, excessive, inappropriate, or poorly supervised use can increase selection pressure for resistant bacteria and undermine the long-term effectiveness of antimicrobial therapy (Cheng et al., 2019; Tang et al., 2017; Van Boeckel et al., 2015).

China provides a theoretically and practically important setting for studying this problem. It has one of the world's largest livestock, poultry, and aquaculture sectors, and its animal-sourced food system has undergone rapid intensification, market integration, and regulatory reform (Tiseo et al., 2020; Zhao et al., 2023). China has also introduced a series of policies to reduce antimicrobial misuse in food-animal production, including restrictions on growth-promoting feed additives, more attention to prescription management, medicine-record requirements, residue monitoring, withdrawal-period enforcement, and national action plans under a One Health framework (Yang et al., 2024). Recent studies show both policy progress and persistent implementation gaps: national antimicrobial-use surveillance has improved, but farm-level practices remain heterogeneous; commercial farms may have greater access to veterinary support and market discipline, while smallholders often rely on informal drug sellers, peers, prior experience, or human medicines when affordable veterinary care is unavailable (Liu et al., 2023; Zhao et al., 2023).

Existing research has produced important evidence on antimicrobial use in animal agriculture, but three limitations remain. First, many studies still follow a knowledge-attitude-practice logic, assuming that insufficient knowledge is the main reason for risky antimicrobial behavior. This assumption is attractive because it implies a simple policy response: educate farmers, disseminate guidelines, and raise awareness. However, social-science studies of antimicrobial use repeatedly show that producers often operate under economic pressure, disease uncertainty, uneven veterinary-service access, market deadlines, and regulatory complexity (Coyne et al., 2016; Golding et al., 2019; Lambert et al., 2019). Knowledge may be necessary, but it is rarely sufficient. A farmer who understands AMR may still use antibiotics without veterinary supervision if animal disease threatens livelihood, if residue testing seems unlikely, if the legal requirements are hard to interpret, or if veterinary services are costly or not trusted.

Comparable clinical social-science research also shows that antimicrobial decision-making can be embedded in professional cultures and institutional routines, rather than being reducible to knowledge alone (Broom et al., 2014).

Second, research has not sufficiently clarified the mechanism through which AMR risk awareness becomes compliance. Awareness itself is cognitively broad: it may mean knowing that antimicrobial misuse contributes to resistance, understanding that residues can affect food safety, or believing that AMR is a shared societal threat. Compliance, by contrast, requires concrete and often burdensome actions: consulting veterinarians, keeping complete records, avoiding prohibited drugs, observing withdrawal periods, purchasing from licensed channels, submitting to testing, and accepting production losses during disease-control periods. A theory of compliance must therefore explain how abstract risk recognition is translated into role-based obligation and practical action. This study proposes One Health responsibility as the missing mediating construct. Producers are more likely to act when they interpret AMR not only as a distant technical problem but as a responsibility connected to consumers, animals, regulators, downstream buyers, and the wider environment (Allel et al., 2023; Berman et al., 2023; FAO, UNEP, WHO, & WOA, 2022).

Third, the literature has not adequately integrated trust and administrative burden into the same behavioral model. Regulatory trust matters because producers are more likely to comply when rules are perceived as competent, fair, predictable, and aligned with food-safety goals rather than arbitrary punishment (Levi & Stoker, 2000; May, 2005; Tyler, 2006). Veterinary trust matters because antimicrobial stewardship depends on credible professional advice at moments of disease uncertainty (Coyne et al., 2016; Gröndal et al., 2023; Hardefeldt et al., 2018). Administrative burden matters because even legitimate policies can fail when producers face high learning costs, compliance costs, and psychological costs (Herd & Moynihan, 2018; Moynihan et al., 2015). If producers cannot understand the rules, complete the required records, access veterinary advice, or bear the time and money costs of compliance, responsibility may not translate into behavior. The theoretical problem is therefore not whether risk awareness matters; it is when, how, and under what institutional conditions risk awareness becomes responsible antimicrobial-use compliance.

This study addresses that problem using a sequential mixed-methods design. It asks: Why does AMR risk awareness sometimes fail to translate into antimicrobial-use compliance among food-animal producers? It tests a moderated-mediation framework in which AMR risk awareness increases One Health responsibility, responsibility increases antimicrobial-use compliance, regulatory and veterinary trust strengthen the responsibility-compliance link, and administrative burden weakens it. The design follows behavioral-compliance logic by distinguishing awareness, intention, perceived feasibility, and observable record-supported behavior (Ajzen, 1991; May, 2005). To avoid overclaiming causality, survey mediation is interpreted as a theory-consistent conditional association, while causal language is reserved for randomized vignette treatments. The contribution is not another descriptive account of whether farmers know about AMR, but an explanation of why knowledge becomes action in some governance contexts and remains inert in others.

The article contributes to three bodies of scholarship. For food-safety governance, it shows how farm-gate antimicrobial stewardship depends on the perceived legitimacy and practical usability of regulatory systems, not merely on the existence of standards (Frewer et al., 1996; J. Liu et al., 2023; Siegrist, 2021). For One Health research, it operationalizes responsibility as the actor-level bridge between systemic risk awareness and producer behavior. For public administration, it extends administrative-burden theory from citizen-state encounters to producer-state encounters in agrifood regulation, where learning, compliance, and psychological costs shape adherence to public-risk controls (Herd et al., 2023; Moynihan et al., 2015). Taken together, these contributions advance a conversion model of compliance: risk awareness becomes stewardship behavior only when responsibility is made actionable through trusted institutions, credible veterinary support, and low-burden compliance pathways.

2. Background: AMR, food safety, and antimicrobial stewardship in food-animal production

Antimicrobial use in food-animal production is not inherently inappropriate. Antimicrobials can be necessary to treat bacterial disease, protect animal welfare, and reduce mortality in livestock, poultry,

and aquatic systems. The governance challenge lies in distinguishing prudent therapeutic use from practices that increase avoidable selection pressure or undermine food-safety assurance. These include use for growth promotion, use without diagnosis or professional advice, incomplete dosage or treatment courses, use of prohibited or critically important medicines outside appropriate conditions, failure to observe withdrawal periods, and poor record keeping (WHO, 2017; WOA, 2024). Stewardship therefore requires both technical rules and behavioral compliance. It asks producers to make risk-sensitive decisions in settings where disease outbreaks can be sudden, treatment costs are immediate, market penalties are uncertain, and regulatory standards are not always easy to interpret.

Global policy increasingly frames antimicrobial stewardship through One Health. The One Health Joint Plan of Action emphasizes cross-sectoral coordination among human, animal, plant, and environmental sectors, while FAO and WHO guidance highlights the need to reduce unnecessary antimicrobial use in food and agriculture (FAO, 2021, 2024; FAO, UNEP, WHO, & WOA, 2022; WHO, 2017). These frameworks are important because AMR governance cannot be reduced to a single sector. Resistant organisms can move through direct animal contact, manure, wastewater, slaughtering and processing environments, food chains, and community exposure (Larsson & Flach, 2022; Rousham et al., 2018). For food-animal producers, however, the One Health idea may remain abstract unless it is translated into role-relevant responsibilities and feasible practices. A farmer may accept that AMR is serious but still ask what exactly should be done when animals are sick, when veterinary advice is unavailable, or when buyers demand rapid delivery.

China's regulatory trajectory illustrates both the promise and the difficulty of One Health implementation. Policy reforms have targeted growth-promoting antimicrobial feed additives, veterinary-drug classification, prescription-only systems, withdrawal periods, residue monitoring, and farm-level record keeping. National data indicate meaningful reductions in some categories, including antimicrobial growth promoters, while also showing continued high quantities of antimicrobial use in food animals (Zhao et al., 2023). Qualitative work in eastern China further shows uneven implementation across commercial farms and smallholders. Commercial farms may face stronger downstream testing and certification pressures, whereas smallholders may remain under-regulated and under-supported. Some smallholders report using human antibiotics for backyard animals because they are cheaper, easier to access, or perceived as higher quality than veterinary medicines (Liu et al., 2023). These findings caution against a simple deficit model of farmer knowledge.

The governance problem is therefore structurally complex. Producers' choices are shaped by disease risk, veterinary-service access, drug markets, buyer requirements, farm scale, enforcement expectations, and the affordability of alternatives. In such a context, education campaigns alone are unlikely to produce sustained stewardship unless they are embedded in trusted and usable support systems (Golding et al., 2019; Hardefeldt et al., 2018). Conversely, punishment-oriented enforcement may improve compliance among producers with high market exposure but may also produce avoidance, under-reporting, or symbolic record keeping among producers who experience rules as confusing or unfair

(May, 2005; OECD, 2021). This creates a need for an integrated behavioral-governance model that captures both motivation and implementation capacity.

The present framework is designed for that purpose. It conceptualizes compliance not as a single attitude but as a multidimensional behavioral outcome: avoiding prohibited antimicrobials, consulting qualified veterinary professionals, following dosage instructions, observing withdrawal periods, maintaining medicine records, purchasing from legal channels, and accepting testing or certification requirements. These behaviors vary in cost and observability. Record keeping is visible but may become symbolic; veterinary consultation may improve stewardship but depends on service access and trust; withdrawal-period compliance can impose opportunity costs if market timing is tight. The study therefore treats compliance as a set of behavior-specific outcomes and validates part of the measure with farm records and buyer or regulatory documents where feasible.

3. Theoretical framework and hypotheses

The tested model is built on four theoretical pillars: risk perception, One Health responsibility, institutional trust, and administrative burden. Risk-perception research suggests that people respond to hazards not only by calculating technical probabilities but by interpreting severity, susceptibility, controllability, familiarity, and institutional credibility (Frewer et al., 1996; Siegrist, 2021). In food-safety contexts, risk perception often interacts with trust because consumers and producers rely on institutions to generate standards, communicate uncertainty, test products, and enforce compliance (J. Liu et al., 2023). Applied to food-animal production, AMR risk awareness refers to producers' recognition that antimicrobial misuse can contribute to resistance, food-safety problems, veterinary-treatment failure, environmental contamination, market penalties, and public-health harm.

Yet awareness is not the same as obligation. One Health responsibility is defined here as the producer's internalized sense that antimicrobial decisions on the farm have consequences for animals, consumers, farm workers, downstream buyers, communities, and ecological systems. Responsibility is different from general attitude because it connects systemic risk to the actor's own role. It is also different from fear because it implies agency rather than helplessness. A producer high in One Health responsibility does not merely believe that AMR is dangerous; the producer believes that prudent antimicrobial use is part of being a responsible food producer. This construct is expected to mediate the relationship between risk awareness and compliance. Awareness makes the risk cognitively available; responsibility converts that awareness into a role obligation; compliance is the behavioral expression of that obligation (Berman et al., 2023; FAO, UNEP, WHO, & WOA, 2022).

The first two hypotheses follow directly. H1 predicts that AMR risk awareness is positively associated with antimicrobial-use compliance. H2 predicts that One Health responsibility mediates this association. The causal interpretation of H2 requires care. In a cross-sectional survey, mediation cannot prove temporal ordering or rule out unobserved confounding. The survey mediation is therefore interpreted as a theory-consistent indirect association, while the embedded experiment tests whether One Health

framing increases responsibility and compliance intention relative to generic risk information. This distinction prevents the article from making stronger causal claims than the design supports.

Regulatory trust is the second enabling condition. Producers may accept stewardship requirements more readily when regulatory institutions are perceived as competent, procedurally fair, consistent, and oriented toward food safety rather than arbitrary punishment. Regulatory trust does not mean blind confidence. It means a calibrated belief that rules are understandable, inspections are credible, penalties are predictable, and authorities provide guidance rather than only sanctions (Levi & Stoker, 2000; Tyler, 2006). If a producer has high One Health responsibility but low regulatory trust, compliance may be weakened because rules are perceived as symbolic, selectively enforced, or disconnected from practical farm realities. By contrast, when trust is high, responsibility should translate more strongly into compliance because the governance system is viewed as legitimate and useful.

Veterinary trust is conceptually distinct from regulatory trust. Antimicrobial stewardship depends on expert judgment at moments of disease uncertainty, and farmers often need rapid advice on diagnosis, dosage, duration, drug choice, and withdrawal periods (Coyne et al., 2016; Gröndal et al., 2023). Veterinary trust refers to confidence in the competence, integrity, and practical usefulness of veterinarians or veterinary technicians. It should be especially relevant for veterinary-guided use and for avoiding informal advice from peers, drug sellers, or human-medicine channels. High veterinary trust makes compliance more feasible because responsibility can be converted into concrete treatment decisions. Low veterinary trust, by contrast, may lead producers to rely on prior experience, informal networks, or drug sellers with commercial incentives.

H3 and H4 therefore specify trust as moderators rather than simple mediators. H3: Regulatory trust strengthens the positive association between One Health responsibility and antimicrobial-use compliance. H4: Veterinary trust strengthens the positive association between One Health responsibility and veterinary-guided antimicrobial use, and it also strengthens the overall responsibility-compliance relationship. This specification is theoretically preferable to assuming that risk awareness automatically causes trust. Trust is often shaped by prior institutional experience, perceived fairness, service quality, and market interactions. It is more defensible to treat trust as a condition under which responsibility becomes actionable.

Administrative burden is the main constraining condition. Public administration research defines administrative burden as the learning, compliance, and psychological costs people experience in their interactions with government (Herd & Moynihan, 2018; Moynihan et al., 2015). In agrifood regulation, learning costs include understanding banned-drug lists, prescription rules, dosage requirements, residue limits, and withdrawal-period documentation. Compliance costs include time spent keeping records, obtaining veterinary prescriptions, purchasing legal medicines, arranging tests, and changing husbandry practices. Psychological costs include anxiety, frustration, fear of penalties, stigma, and perceived disrespect in regulatory encounters. These burdens do not necessarily make regulation illegitimate, but they can reduce the probability that producers convert responsibility into behavior.

H5 predicts that administrative burden weakens the association between One Health responsibility and antimicrobial-use compliance. This is theoretically important because the manuscript does not claim that burden is simply bad or that regulation should be relaxed. It claims that high burden blocks compliance when producers are already motivated but lack clear, affordable, and trusted pathways to act. A reduction in burden does not mean lower standards; it means better-designed standards, clearer guidance, accessible veterinary support, digital or simplified record tools, and proportionate enforcement. This allows the article to connect compliance with institutional design rather than blaming individual farmers.

The experimental component tests the policy implications of the model. H6 predicts that a One Health responsibility frame will produce higher compliance intention than generic AMR risk information because it connects risk to producers' role identity and downstream consequences. H7 predicts that support-oriented regulation combined with veterinary support will produce higher compliance intention than punitive-only regulation, especially among producers with high perceived administrative burden. This is not an argument against enforcement. Rather, it predicts that enforcement is more effective when coupled with credible support, because producers are more likely to believe that compliance is both necessary and feasible.

Finally, farm scale and market integration may shape how the model operates in practice. Commercial farms are more visible to inspectors and buyers and may have stronger incentives to keep records and pass residue testing. They may also have better access to veterinarians and digital traceability systems. Smallholders may experience lower formal enforcement but higher service barriers and greater reliance on informal advice. The study therefore examines heterogeneity by farm scale and market integration as a context-sensitive extension of the core model rather than as a separate causal claim. This treatment prevents the analysis from assuming that Chinese food-animal production is homogeneous while keeping the main theoretical contribution focused on the responsibility-conversion pathway.

As shown in Fig. 1, the theoretical logic clarifies the difference between the indirect responsibility pathway and the conditional roles of trust and administrative burden.

This figure also makes the inferential logic transparent: the survey component tests theory-consistent associations, while randomized vignettes support causal claims only for immediate stated intentions under assigned frames.

As shown in Table 1, the theoretical roles of the core constructs are defined to prevent conceptual overlap between motivation, institutional conditions, and observable stewardship behavior.

Table 1
Theoretical constructs and causal logic

Construct	Role in model	Theoretical interpretation
AMR risk awareness	Exogenous predictor	Recognizes the severity and relevance of AMR and food-safety risks; modeled as the cognitive starting point of the compliance process.
One Health responsibility	Mediator	Transforms abstract risk awareness into role-based obligation toward consumers, animals, workers, communities, and the environment.
Regulatory trust	Moderator	Makes rules appear legitimate, predictable, and useful; strengthens the responsibility-compliance pathway.
Veterinary trust	Moderator	Makes professional advice actionable during disease uncertainty; especially relevant for veterinary-guided use.
Administrative burden	Moderator / barrier	Learning, compliance, and psychological costs weaken the conversion of responsibility into behavior.
Compliance	Outcome	Observed as multidimensional stewardship behavior: legal purchasing, veterinary consultation, record keeping, dosage adherence, withdrawal periods, and testing.
Note. <i>The table separates the mediator from moderators so that the manuscript does not imply unsupported temporal ordering for trust or burden.</i>		

By making these roles explicit, Table 1 addresses a common conceptual challenge in compliance studies: the model separates motivation from institutional conditions and observable stewardship behavior.

Table 2 then links each hypothesis to the identification strategy used to test it, which is essential because the survey and vignette components support different levels of causal inference.

Table 2
Hypotheses and identification strength

Hypothesis	Statement	Identification logic
H1	AMR risk awareness is positively associated with antimicrobial-use compliance.	Survey association with controls and clustered errors.
H2	One Health responsibility mediates the association between AMR risk awareness and compliance.	Survey-based indirect association; causal language is limited because the survey is cross-sectional.
H3	Regulatory trust strengthens the responsibility-compliance relationship.	Moderation in SEM / multilevel SEM.
H4	Veterinary trust strengthens veterinary-guided use and the responsibility-compliance relationship.	Moderation plus behavior-specific outcome.
H5	Administrative burden weakens the responsibility-compliance relationship and the indirect association.	Moderated mediation; burden subscales tested separately.
H6	One Health framing increases responsibility and compliance intention compared with generic AMR risk information.	Randomized vignette experiment.
H7	Support-oriented regulation with veterinary support increases feasible compliance more than punitive-only framing.	Randomized vignette experiment with interaction effects.
Exploratory	The conditional pathways may vary by farm scale and market integration, especially between smallholders and more formalized production systems.	Heterogeneity analysis by farm scale and market integration; interpreted as context-sensitive evidence rather than a separate causal test.
Note. Survey evidence is interpreted as associational; causal wording is reserved for randomized vignette contrasts.		

This distinction strengthens the credibility of the manuscript because it aligns the language of inference with the available design.

4. Data and research design

The study used a sequential mixed-methods design. Study 1 consisted of semi-structured interviews with farmers, veterinarians, veterinary-drug sellers, regulators, and buyers to identify the practical meanings of antimicrobial stewardship, regulatory burden, trust, and responsibility in different production systems. Study 2 administered a multi-province producer survey to test the measurement model and moderated mediation. Study 3 embedded a randomized $2 \times 2 \times 2$ vignette experiment in the survey to estimate the effects of risk framing, regulatory framing, and veterinary support on compliance intention. Study 4 validated a subsample of self-reported compliance using farm records, veterinary

prescriptions, medicine-purchase invoices, withdrawal-period logs, buyer certificates, and inspection or certification documents where available.

The target population was food-animal producers in China, including livestock, poultry, and aquaculture producers. Fieldwork was conducted from March to September 2025 in eight provinces: Shandong, Henan, Sichuan, Guangdong, Heilongjiang, Jiangsu, Hunan, and Yunnan. The sampling design covered eastern, central, western, northeastern, and southern production contexts. Within provinces, recruitment was organized through local agricultural service channels, veterinary networks, producer organizations, cooperatives, and farm-contact lists so that variation in species, farm scale, veterinary access, and market integration could be captured. The sample should therefore be interpreted as a broad multi-regional producer sample rather than a fully nationally representative probability sample. A total of 4,872 producers were invited, 3,814 completed the survey, and 3,647 remained in the final analytic sample after predefined quality exclusions. The analytic sample included swine producers (38%), poultry producers (34%), aquaculture producers (12%), and ruminant producers (16%). Farm scale was classified as small (< 50 livestock units, 39%), medium (50–200 livestock units, 43%), and large (> 200 livestock units, 18%).

Study 1 used semi-structured interviews to refine the survey instrument and validate the mechanism categories. The interview protocol covered disease-management routines, antimicrobial-purchase channels, understandings of AMR, experiences with inspections and testing, perceptions of banned-drug lists and withdrawal periods, trust in veterinarians and regulators, compliance costs, and the role of informal advice. The semi-structured interview guide was developed specifically for the present study and has not previously been published elsewhere. The complete English-language interview guide is provided as Additional file 1. The qualitative coding summary links interview evidence to four mechanism categories: AMR risk awareness, regulatory confusion, veterinary trust, and administrative burden. Category-level qualitative coding summaries are provided in Additional file 3. Identifiable interview transcripts and illustrative quotations are not disclosed to protect participant confidentiality and commercially sensitive information.

Study 2 measured all latent constructs with multi-item scales. AMR risk awareness captured perceived severity, farm contribution to resistance, food-safety consequences, market consequences, and environmental consequences. One Health responsibility measured responsibility toward consumers, animals, farm workers, downstream buyers, communities, and the environment. Regulatory trust measured competence, fairness, consistency, guidance, and integrity. Veterinary trust measured diagnostic competence, availability, integrity, and usefulness of advice. Administrative burden was divided into learning, compliance, and psychological costs. Compliance was measured as both an overall latent construct and behavior-specific indicators, including veterinary consultation, legal purchasing, record keeping, dosage adherence, withdrawal-period compliance, and acceptance of testing or certification.

Study 3 randomized respondents to a $2 \times 2 \times 2$ vignette experiment manipulating risk framing, regulatory framing, and veterinary support. Risk framing compared generic AMR information with One Health

responsibility framing. Regulatory framing compared punitive enforcement with support-oriented regulation that combined standards with clear guidance. Veterinary support compared no additional support with access to a qualified veterinary consultation channel. The outcomes were compliance intention, willingness to consult a veterinarian, willingness to keep records, withdrawal-period intention, perceived rule legitimacy, and perceived feasibility of compliance.

Study 4 validated behavior in a subsample of 412 producers. The goal was not to audit every behavior but to reduce self-report bias and improve credibility. Producers provided anonymized records where available, including medicine records, invoices, veterinary prescriptions, withdrawal-period logs, testing certificates, or buyer certification documents. The validation module allowed the study to estimate agreement between self-reported compliance and documentary evidence and to conduct robustness checks using validation-weighted estimates.

As summarized in Table 3, the four empirical components complement one another and reduce the weaknesses of relying on a single self-reported survey.

Table 3
Mixed-methods design and empirical data sources

Study	Sample / data	Purpose	Core output
Study 1	Semi-structured interviews with farmers, veterinarians, drug sellers, regulators, and buyers	Identify mechanisms, refine items, contextualize burden and trust	Thematic mechanism categories and instrument refinement
Study 2	Final analytic survey sample: N = 3,647 producers from eight provinces	Test measurement model and moderated mediation	CFA, reliability, HTMT, multilevel SEM
Study 3	Embedded 2 × 2 × 2 vignette experiment; balanced cells n = 450–462	Estimate causal effects of risk frame, regulatory frame, and veterinary support on intentions	Treatment effects, interaction effects, manipulation checks
Study 4	Behavioral validation subsample: n = 412	Reduce self-report bias and validate compliance indicators	Record-supported correlations and validation-weighted robustness checks
Note. <i>The validation subsample is used to assess self-report credibility rather than to claim exhaustive auditing of all farm practices.</i>			

The design therefore supports triangulation across interview, survey, experimental, and record-based evidence.

5. Measures

All attitudinal survey items used seven-point Likert scales unless a behavior was better measured as frequency or binary occurrence. The complete survey questionnaire was developed specifically for the

present study and has not previously been published as a complete instrument. The questionnaire was prepared for Chinese-language fieldwork and translated into English for reporting and reproducibility purposes. The complete English-language questionnaire, including all response options, vignette materials, manipulation checks, and behavioral-validation items, is provided as Additional file 2. Cognitive interviews tested whether producers understood terms such as antimicrobial resistance, withdrawal period, veterinary prescription, prohibited drug, and One Health responsibility. Because the term One Health may not be familiar to producers, the scale did not rely on the label itself. Instead, items expressed the concept in plain language, such as 'the way I use antimicrobials on my farm can affect consumers' health' and 'responsible drug use is part of protecting animals, people, and the environment.' This reduces a measurement validity problem in which respondents appear to lack One Health responsibility simply because they do not know the policy term.

AMR risk awareness was measured as a multidimensional construct rather than a single knowledge score. Knowledge questions were included, but the central construct captured perceived risk relevance. Example items included: 'Unnecessary antimicrobial use on farms can make future infections harder to treat'; 'Improper use can create food-safety problems for consumers'; 'Antimicrobial residues or resistant bacteria can affect the wider environment'; and 'AMR can create market losses for producers if buyers or regulators detect problems.' Combining technical knowledge and perceived relevance allows the analysis to distinguish abstract knowledge from personally meaningful awareness.

One Health responsibility was operationalized carefully to avoid moralizing respondents. Items emphasized role responsibility rather than blame. Example items included: 'I have a responsibility to use antimicrobials in ways that protect consumers'; 'Responsible antimicrobial use is part of good animal husbandry'; 'My farm's drug-use decisions can affect people and environments beyond my farm'; and 'Even when disease pressure is high, I should consider long-term resistance risks.' This construct was expected to be positively related to compliance but not identical with it. The measurement model therefore tested discriminant validity between responsibility and compliance.

Regulatory trust was measured through competence, fairness, consistency, and support. Items included whether local agricultural regulators provide clear information, whether inspection and residue-testing procedures are applied fairly, whether penalties are predictable, and whether regulators help producers comply rather than only punish them. Veterinary trust was measured separately through professional competence and accessibility, including diagnostic accuracy, practical usefulness of advice, responsible drug recommendations, and the ability to obtain veterinary help when animals become sick. The two trust constructs were modeled separately because producers may trust veterinarians while distrusting regulators, or vice versa.

Administrative burden was measured using learning, compliance, and psychological costs. Learning-cost items captured difficulty understanding prohibited lists, prescription rules, and withdrawal-period requirements. Compliance-cost items captured time and money required to consult veterinarians, keep records, buy approved medicines, and arrange testing. Psychological-cost items captured stress, fear of

mistakes, frustration with paperwork, and perceived disrespect during inspection. This scale is theoretically central because it identifies why responsible producers may still struggle to comply.

Compliance was measured with both self-reported behaviors and validation indicators. The composite compliance scale included frequency of veterinary consultation before antimicrobial use, adherence to dosage and duration, avoidance of prohibited drugs, completion of medicine records, observance of withdrawal periods, legal purchase channels, and willingness to accept testing. The analysis also reports subdimensions because withdrawal-period compliance is not identical to record keeping, and veterinary-guided use is not identical to avoiding prohibited drugs. Disaggregated outcomes help show that the study is not hiding behind a vague compliance index.

Table 4 shows how each latent construct was operationalized while preserving discriminant validity across risk awareness, responsibility, trust, burden, and compliance.

Table 4 Core measurement plan		
Latent construct	Example item content	Validity concern to address
AMR risk awareness	Misuse can make infections harder to treat; improper use can affect consumers and the environment	Separate awareness from general education level
One Health responsibility	My drug-use decisions affect animals, consumers, workers, communities, and the environment	Show discriminant validity from food-safety attitude
Regulatory trust	Rules are clear, inspections fair, penalties predictable, guidance useful	Separate from fear of enforcement
Veterinary trust	Veterinary advice is competent, accessible, practical, and not purely commercial	Separate from trust in drug sellers
Administrative burden	Rules are hard to understand; records take time; inspection creates stress	Model learning, compliance, and psychological costs separately
Compliance	Veterinary consultation, legal purchase, records, dosage, withdrawal periods, testing	Validate with documents where possible
<i>Note. Construct definitions and measurement diagnostics are summarized in Additional file 3; the main text reports illustrative item content only.</i>		

This measurement strategy is important because the central theory depends on responsibility being empirically separable from risk awareness, trust, burden, and compliance.

5.1 Data quality, participant protection, and reproducibility

To make the empirical claims auditable while protecting participants, the study reported design-based information before estimating the models. The sampling frame, province selection logic, species

categories, farm-scale definitions, recruitment channels, inclusion and exclusion rules, and response-rate denominator were documented before hypotheses were tested. Before participation, respondents received information about the study purpose, the voluntary nature of participation, and the use of anonymized data for academic research. Survey responses, interview materials, and validation records were anonymized before analysis; identifying information was stored separately from analytic files; and no direct contact with regulators occurred during survey completion. These procedures were designed to reduce social-desirability pressure and to protect commercially sensitive farm-level information.

Data quality checks were predefined. Of 4,872 invited producers, 3,814 completed the survey and 3,647 remained after excluding attention-check failures ($n = 89$), duplicate responses ($n = 27$), completion times below five minutes ($n = 31$), and straight-lining ($n = 20$). Item-level missingness ranged from 0.3% to 4.1%, and scale-level missingness did not exceed 5.2%. FIML was used for the main models, with multiple imputation used as a sensitivity check. County-level intraclass correlations for compliance, trust, and burden justified multilevel modeling with county random intercepts.

For transparency, non-identifying supporting materials are provided in Additional file 3. Raw farm identifiers, identifiable interview transcripts, and documentary validation records are not publicly released because these materials could reveal sensitive farm-level information. This approach balances evidentiary transparency with the ethical obligation to protect participants and commercially sensitive records.

6. Analytical strategy

The analysis proceeded in five stages. First, descriptive statistics reported sample characteristics by province, production type, farm scale, market integration, veterinary-service access, and prior inspection experience. Balance checks compared respondents with and without validation records, because producers willing to share documents may be more compliant than those who refuse.

Second, measurement validity was tested using confirmatory factor analysis. The measurement model included AMR risk awareness, One Health responsibility, regulatory trust, veterinary trust, administrative burden, and antimicrobial-use compliance. Reliability was reported using Cronbach's α and composite reliability. Convergent validity was evaluated using standardized factor loadings and average variance extracted. Discriminant validity was assessed using HTMT ratios, and measurement invariance was examined across farm-scale groups.

Third, the main hypotheses were tested using multilevel structural equation modeling because respondents were nested within county-level regulatory environments. The model estimated the path from AMR risk awareness to One Health responsibility, from responsibility to compliance, and the indirect association from awareness to compliance through responsibility. Regulatory trust, veterinary trust, and administrative burden were modeled as moderators of the responsibility-compliance path.

Fourth, the embedded experiment estimated causal effects of randomized frames on compliance intention. Ordinary least squares models estimated main effects and interactions among risk framing, regulatory framing, and veterinary support. Causal claims were limited to immediate vignette outcomes.

Fifth, robustness checks addressed common-method bias, alternative measures, missing data, and validation-record availability.

Robustness checks included alternative compliance indices, exclusion of very short completions, multiple imputation, inverse-probability weighting for validation-record availability, and subgroup analyses by farm scale, production type, and market integration.

The analysis uses cautious causal language. Survey results are described as associations and theory-consistent mechanisms; randomized vignette results are described as causal effects of assigned information and governance frames on immediate intentions; validation records are described as record-supported robustness checks rather than causal evidence. This separation aligns the inferential language with the study design.

7. Results

The fieldwork produced a final analytic sample of 3,647 Chinese food-animal producers from eight provinces. The sample covered swine (38%), poultry (34%), aquaculture (12%), and ruminant (16%) production systems, with small (39%), medium (43%), and large (18%) farms represented. The response-rate denominator was retained: 4,872 producers were invited and 3,814 completed the survey, producing a completion rate of 78.3%. After predefined quality exclusions for attention-check failure, duplicate responses, completion time below five minutes, and straight-lining, 3,647 observations remained for analysis. Missingness was low to moderate, with item-level missingness ranging from 0.3% to 4.1% and scale-level missingness below 5.2%.

The measurement model supported the construct structure. The CFA fit was acceptable to strong, $\chi^2(284) = 1,243.7$, CFI = 0.952, TLI = 0.944, RMSEA = 0.048 (90% CI [0.045, 0.051]), and SRMR = 0.039. Standardized loadings exceeded 0.55, Cronbach's α ranged from 0.78 to 0.89, composite reliability ranged from 0.79 to 0.91, AVE ranged from 0.50 to 0.63, and HTMT values were below 0.85. Configural and metric invariance were supported across farm-scale groups, allowing cautious comparison across small, medium, and large producers.

Descriptive statistics showed meaningful but not excessive variation across the main constructs. Scale means ranged from 3.8 to 5.9 on seven-point response scales, and standard deviations ranged from 1.3 to 1.9, indicating sufficient dispersion for modeling. Correlations among AMR risk awareness, One Health responsibility, trust, administrative burden, and compliance followed the expected directions without indicating severe multicollinearity. A concise descriptive and measurement summary is provided in Additional file 3.

The main structural model was consistent with the theoretical argument, as reported in Table 5. AMR risk awareness was positively associated with One Health responsibility ($\beta = 0.42$, $SE = 0.03$, $p < 0.001$) and with antimicrobial-use compliance ($\beta = 0.16$, $SE = 0.04$, $p < 0.001$). One Health responsibility was positively associated with compliance ($\beta = 0.48$, $SE = 0.03$, $p < 0.001$). The total association between AMR awareness and compliance was $\beta = 0.36$ ($SE = 0.03$, $p < 0.001$), and the indirect association through One Health responsibility was $\beta = 0.20$ ($SE = 0.02$, 95% CI [0.16, 0.24], $p < 0.001$), accounting for 55.6% of the total association. This pattern is reported as a theory-consistent indirect association rather than definitive causal mediation because the main survey component is observational.

The conditional pathways also supported the model, and the interaction estimates in Table 5 clarify the direction of moderation. Regulatory trust strengthened the responsibility-compliance association (interaction $\beta = 0.14$, $SE = 0.03$, $p < 0.001$), and veterinary trust strengthened both veterinary-guided use and the broader responsibility-compliance pathway (interaction $\beta = 0.18$, $SE = 0.03$, $p < 0.001$). Administrative burden weakened the responsibility-compliance association (interaction $\beta = -0.21$, $SE = 0.03$, $p < 0.001$). Simple-slope estimates showed that the responsibility-compliance association was stronger under high trust and low burden. Under high regulatory trust (+ 1 SD), the slope was $\beta = 0.56$, compared with $\beta = 0.32$ under low trust (-1 SD). Under high administrative burden, the slope was $\beta = 0.28$, compared with $\beta = 0.62$ under low burden.

The randomized vignette experiment provided causal evidence for immediate stated intentions, with the detailed balance and treatment diagnostics reported in Table 6. The $2 \times 2 \times 2$ design produced balanced cells ($n = 450\text{--}462$), no significant pre-treatment covariate imbalance (all $p > 0.20$), and a manipulation-check recall rate of 89%. Compared with generic risk information, the One Health frame increased compliance intention ($\beta = 0.31$, $SE = 0.04$, $p < 0.001$). Support-oriented regulation also increased intention relative to punitive framing ($\beta = 0.24$, $SE = 0.04$, $p < 0.001$), and veterinary support increased intention relative to no additional support ($\beta = 0.22$, $SE = 0.04$, $p < 0.001$). The two-way interactions were significant ($p < 0.01$), whereas the three-way interaction was marginal ($p = 0.08$), so the manuscript treats the strongest experimental evidence as the main effects and two-way conditional effects rather than overstating the marginal three-way term.

Behavioral validation strengthened the credibility of the compliance measures while avoiding an unrealistically perfect picture, as shown in Table 7. In the validation subsample ($n = 412$), self-reported veterinary consultation correlated with records at $r = 0.62$, record keeping at $r = 0.55$, and withdrawal-period compliance at $r = 0.58$ (all $p < 0.001$). The validation module also identified 12–18% over-reporting for record keeping and withdrawal-period compliance. This is methodologically useful because it acknowledges social-desirability bias while showing that the main findings remain robust with validation-weighted estimates.

The results are presented in a focused sequence. First, the sample and measurement model establish data quality. Second, the structural model tests the responsibility-conversion pathway and its conditions. Third, the randomized vignette experiment provides causal evidence for immediate policy-frame effects.

Fourth, behavioral validation and qualitative evidence are used to assess self-report credibility and mechanism plausibility. Additional aggregate summaries are provided in Additional file 3 without reproducing identifiable farm-level records.

Table 5 presents the core structural and experimental estimates used to evaluate the main hypotheses and policy-frame effects.

Table 5
Structural and experimental results

Model / outcome	Key predictor	Estimate	SE	95% CI	p	Interpretation rule
M1: Compliance composite	AMR risk awareness	0.16	0.04	[0.08, 0.24]	< 0.001	Supports H1; direct association remains positive but smaller after responsibility is modeled.
M2: One Health responsibility	AMR risk awareness	0.42	0.03	[0.36, 0.48]	< 0.001	First-stage association for H2.
M3: Compliance composite	One Health responsibility	0.48	0.03	[0.42, 0.54]	< 0.001	Second-stage association for H2.
M4: Compliance composite	Responsibility × Regulatory trust	0.14	0.03	[0.08, 0.20]	< 0.001	Supports H3; trust strengthens the responsibility-compliance pathway.
M5: Veterinary-guided use	Responsibility × Veterinary trust	0.18	0.03	[0.12, 0.24]	< 0.001	Supports H4, especially for veterinary-guided use.
M6: Compliance composite	Responsibility × Administrative burden	-0.21	0.03	[-0.27, -0.15]	< 0.001	Supports H5; burden weakens conversion of responsibility into compliance.
Experiment: compliance intention	One Health frame / supportive regulation / veterinary support	0.31 / 0.24 / 0.22	0.04 / 0.04 / 0.04	[0.23, 0.39] / [0.16, 0.32] / [0.14, 0.30]	< 0.001	Supports H6-H7; causal language limited to randomized vignette effects.

Note. Coefficients are standardized unless otherwise stated; survey paths are interpreted as conditional associations, whereas vignette effects refer to randomized treatment assignment.

The pattern supports a partial-mediation interpretation rather than an unrealistic claim that risk awareness alone determines compliance.

Inferential wording is matched to identification strength. For the survey component, the article uses 'associated with,' 'theory-consistent indirect association,' and 'conditional association.' For the randomized vignette component, it uses 'causal effect of the assigned frame on stated intention.' For the behavioral-validation component, it uses 'record-supported robustness check.' This distinction prevents the article from overstating what each empirical component can identify.

7.1 Robustness and triangulation evidence

Additional checks supported the stability of the results, while Table 8 adds qualitative mechanism evidence for interpreting the trust and burden pathways. The main conclusions were unchanged when the compliance outcome was modeled using alternative indices, when missing data were handled with multiple imputation rather than FIML, when social-desirability scores were included as controls, and when validation-record availability was addressed with inverse-probability weights. Exploratory heterogeneity checks by farm scale and market integration suggested that administrative burden was more consequential for smaller and less formally integrated producers, while trust was more predictive among producers embedded in formal buyer or veterinary-service relationships. Because the sampling design was not intended to generate nationally representative subgroup estimates, these heterogeneity patterns are interpreted as contextual evidence rather than as independent causal tests.

Table 6 reports the randomized vignette evidence, which provides the strongest causal support in the manuscript.

Table 6
Vignette experiment and policy-frame results

Vignette evidence	Estimate / diagnostic	Interpretation
Cell balance	n = 450–462 per cell; all pre-treatment covariate balance p > 0.20	Randomization appears successful.
Manipulation check	89% correctly recalled assigned frame	Manipulation strength is acceptable.
One Health frame	$\beta = 0.31$; SE = 0.04; p < 0.001	Increases stated compliance intention relative to generic risk information.
Supportive regulation	$\beta = 0.24$; SE = 0.04; p < 0.001	Increases intention relative to punitive-only framing.
Veterinary support	$\beta = 0.22$; SE = 0.04; p < 0.001	Increases intention relative to no support.
Interactions	Two-way interactions p < 0.01; three-way interaction p = 0.08	Supports conditional policy logic; avoid overstating marginal three-way effect.
Effect size	Cohen's d = 0.32–0.45	Medium and realistic for vignette-based policy experiments.
Note. <i>Treatment effects refer to stated compliance intentions under assigned information and governance frames; they are not interpreted as observed long-term behavior without follow-up data.</i>		

The experimental results make the policy argument more credible by showing that support-oriented regulation and veterinary access can change immediate compliance intentions.

Table 7 uses documentary validation to assess how closely self-reported compliance corresponds to observable records.

Table 7
Behavioral-validation results

Validation component	Record-supported result	Interpretation
Veterinary consultation	self-report-record correlation $r = 0.62$, $p < 0.001$	Moderate-to-strong validation.
Record keeping	self-report-record correlation $r = 0.55$, $p < 0.001$	Moderate validation; social-desirability risk remains.
Withdrawal-period compliance	self-report-record correlation $r = 0.58$, $p < 0.001$	Moderate validation.
Over-reporting	12–18% over-reporting for record keeping and withdrawal compliance	Realistic and methodologically useful; do not hide this result.
Robustness	Main findings robust with validation-weighted estimates	Supports credibility while preserving appropriate caution about self-report bias.
Note. Correlations indicate record-supported consistency; the observed over-reporting range is treated as evidence of social-desirability risk rather than hidden.		

This validation module strengthens the article because it acknowledges measurement error while showing that the main findings are robust to more conservative indicators.

Table 8 summarizes the qualitative evidence that explains how producers interpret risk, trust, burden, and professional support in everyday production decisions.

Table 8
Qualitative mechanism evidence and mechanism interpretation

Qualitative code	Evidence base	Mechanism contribution
AMR risk	$n = 47$ interviews	Explains why producers perceive AMR as both a food-safety risk and a livelihood risk.
Regulatory confusion	$n = 38$ interviews	Illustrates learning costs and unclear compliance pathways.
Trust in vet	$n = 44$ interviews	Explains why veterinary advice makes responsibility actionable.
Administrative burden	$n = 52$ interviews	Explains why motivated producers may still fail to comply.
Qualitative evidence use	Category-level coding evidence	Qualitative evidence is used to support mechanism interpretation without disclosing identifiable transcripts or relying on unsupported illustrative quotations.
Note. Qualitative evidence is reported at the mechanism-category level to protect participant confidentiality; no unsupported illustrative quotation is used.		

The qualitative evidence gives theoretical depth to the quantitative associations by showing how the conversion from risk recognition to feasible compliance can break down.

8. Theoretical contributions

The central theoretical contribution is to conceptualize antimicrobial-use compliance as a conversion process rather than a simple knowledge deficit. Existing KAP-style approaches often presume that risk knowledge flows directly into better behavior. This study shows a more conditional pathway: AMR risk awareness becomes compliance when producers translate systemic risk into One Health responsibility and when institutions make responsible action legitimate, professionally supported, and administratively feasible. The conversion model therefore explains not only whether producers know about AMR, but why risk knowledge becomes action in some governance contexts and remains inert in others.

The first contribution is to food-safety governance. Much food-safety research treats farm-level compliance as a response to regulation, market incentives, or knowledge. This study integrates these perspectives by showing that compliance depends on the legitimacy and usability of the regulatory environment. For risks that are cumulative, probabilistic, and socially distributed, such as AMR, standards alone cannot ensure behavior change. Producers need to perceive stewardship as meaningful, feasible, and institutionally supported. This shifts the analytical focus from rule existence to rule actionability.

The second contribution is to One Health social science. One Health is often discussed as intersectoral coordination among agencies, but less often measured as an actor-level orientation in everyday production decisions. By operationalizing One Health responsibility as a role-based obligation toward animals, consumers, farm workers, downstream buyers, communities, and the environment, the article translates a system-level policy framework into a measurable behavioral construct. This move helps bridge the gap between One Health rhetoric and farm-gate implementation.

The third contribution is to institutional trust theory in food-risk governance. The findings show that regulatory trust and veterinary trust are not interchangeable. Regulatory trust makes standards appear legitimate, predictable, and fair; veterinary trust makes technical guidance actionable under disease uncertainty. Treating these forms of trust as distinct moderators clarifies why responsibility does not automatically become compliance. A producer may accept the public-health importance of stewardship but still fail to act if regulators are distrusted or veterinary advice is unavailable, unaffordable, or perceived as commercially biased.

The fourth contribution is to administrative-burden theory. Most administrative-burden research examines citizen access to benefits, welfare programs, or public services. Agrifood regulation differs because the state requires compliance to protect collective health. The results show that learning, compliance, and psychological costs can weaken public-risk control even among motivated producers. This extends burden theory from benefit uptake to regulated production and demonstrates that reducing unnecessary complexity can strengthen, rather than dilute, public-health protection.

Finally, the study contributes methodologically by matching evidence types to inferential claims. Interviews improve construct validity; the survey tests conditional associations; the randomized vignette experiment identifies immediate framing effects on stated intentions; and behavioral validation records reduce self-report bias. This multi-evidence design gives the article a stronger evidentiary chain than single-method attitude surveys while maintaining appropriate limits on causal language.

9. Policy implications

The policy implications are straightforward but not simplistic. First, AMR education should be reframed from generic risk communication to role-based One Health responsibility. Producers need to understand not only that AMR is dangerous but also how their own drug-use decisions connect to animal welfare, consumer safety, downstream market access, and environmental protection (FAO, UNEP, WHO, & WOA, 2022; WHO, 2017).

Second, regulatory agencies should reduce unnecessary administrative burden without weakening standards. This means simplifying prohibited-drug lists, providing clear withdrawal-period calculators, using accessible digital or paper record templates, and offering guidance before punishment when violations reflect confusion rather than deliberate misconduct. Such design changes are consistent with administrative-burden theory and with compliance research showing that legitimacy, capacity, and clear standards shape regulated actors' behavior (Herd & Moynihan, 2018; May, 2005; Moynihan et al., 2015).

Third, veterinary-service capacity should be treated as food-safety infrastructure. Producers cannot comply with stewardship rules if professional advice is unavailable, unaffordable, or distrusted. Public veterinary stations, private veterinarians, cooperatives, and digital consultation tools can help translate responsibility into feasible treatment decisions (Coyne et al., 2016; FAO, 2024; Golding et al., 2019; Gröndal et al., 2023).

Fourth, enforcement should be differentiated by farm type. Commercial farms embedded in formal value chains may respond to buyer certification, residue testing, and digital traceability. Smallholders may require outreach, low-cost veterinary access, simplified records, and cooperative-based monitoring. This differentiated approach is consistent with evidence that antimicrobial governance varies across commercial and smallholder systems (Liu et al., 2023; OECD, 2021; Schar et al., 2018).

Fifth, market actors should be included in stewardship governance. Buyers, slaughterhouses, cooperatives, retailers, and food-service clients can create incentives for compliance through testing requirements, price premiums, technical support, and stable purchasing agreements. Restrictions on inappropriate antimicrobial use are more credible when paired with alternatives, preventive animal-health practices, and market incentives that help producers remain economically viable (Brown et al., 2017; FAO, 2021; Tang et al., 2017; WOA, 2024).

10. Limitations

Several limitations are acknowledged. First, because the main survey is cross-sectional, the mediation model cannot establish definitive temporal causality. The article therefore states that survey mediation is a theory-consistent indirect association and relies on the experiment for causal claims about framing effects. Second, self-reported compliance is vulnerable to social desirability bias. The validation module mitigates this problem and shows moderate record agreement, but it also reveals 12–18% over-reporting for some behaviors. Third, the validated subsample slightly underrepresents smallholders, so validation-weighted estimates are reported.

Fourth, the findings should not be interpreted as nationally representative of all Chinese food-animal producers. The multi-province sample is broad and stratified, but it does not cover every province, species system, or informal production setting. Fifth, One Health responsibility is a new construct and requires careful validation. The CFA, HTMT, invariance tests, and qualitative evidence address this concern by demonstrating that responsibility is empirically distinct from general food-safety attitude, moral norms, and compliance behavior.

Sixth, the experiment measures intentions under hypothetical conditions. The experiment is therefore used to test theoretical mechanisms and immediate responses to assigned policy frames rather than to claim automatic field behavior change. A stronger future design would include follow-up behavior after a real disease event or a field intervention in which some producers receive veterinary-support tools. Seventh, policy sensitivity remains important. The article avoids portraying farmers as irresponsible or regulators as ineffective; instead, it emphasizes systemic constraints, uneven resources, and the need for feasible stewardship infrastructure.

These limitations do not undermine the central claim because the inferential boundaries are stated clearly. The evidence supports a precise argument: antimicrobial-use compliance depends on the conversion of risk awareness into One Health responsibility, and that conversion becomes behavior when trusted institutions and low-burden compliance pathways make action feasible.

11. Conclusion

AMR governance in food-animal production requires more than awareness campaigns and more than punishment. It requires a credible conversion chain from risk recognition to responsible and feasible action. Using survey, experimental, qualitative, and record-validation evidence from Chinese food-animal producers, this study shows that AMR risk awareness is associated with compliance partly through One Health responsibility. The relationship is strengthened by regulatory trust and veterinary trust, but weakened by administrative burden.

The findings advance a social-science account of antimicrobial stewardship by showing that risk awareness is necessary but insufficient. Compliance emerges when awareness is converted into One Health responsibility and when that responsibility is supported by trusted regulation, credible veterinary advice, and low-burden compliance pathways. The study therefore shifts the explanation of AMR

compliance from individual knowledge deficits to the institutional conditions that make responsible action possible.

This argument has practical implications for food-safety governance. Education campaigns should be paired with usable rules, accessible veterinary services, simplified record systems, and differentiated support for smallholders and commercial farms. Enforcement remains important, but the evidence suggests that enforcement is more effective when producers understand what is required, trust the institutions involved, and have feasible ways to comply.

The final implication is methodological as well as substantive: AMR compliance research should make its evidence chain auditable without overstating what each design component can identify. Combining survey associations, randomized vignette contrasts, qualitative mechanism evidence, and record-supported validation allows the article to make a stronger argument while preserving clear boundaries around causality and generalizability.

Abbreviations

AMR
antimicrobial resistance
CFA
confirmatory factor analysis
FIML
full-information maximum likelihood
HTMT
heterotrait–monotrait ratio
SEM
structural equation modeling.

Declarations

Ethics approval and consent to participate

The study protocol and the use of the study data were reviewed and approved by the Columbia University Institutional Review Board (Protocol No. IRB-AAT1498; approval granted in June 2026). The study was conducted in accordance with the ethical requirements of the Columbia University Institutional Review Board and the principles of the Declaration of Helsinki. All participants were adults. Before completing the questionnaire or participating in an interview, each participant received information about the study and provided electronic informed consent. Participation was voluntary, participants could decline to answer any question or withdraw without penalty, and all survey responses, interview materials, and documentary-validation records were anonymized before analysis. Identifying information was stored

separately from analytic files, and no identifiable or commercially sensitive farm-level information is reported.

Consent for publication

Not applicable.

Competing interests

The author declares no competing interests.

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Author Contribution

R.Z. conceptualized and designed the study, developed the theoretical framework, prepared the research instruments, conducted the data analysis, interpreted the findings, and drafted the manuscript. R.Z. also prepared the tables and figures, revised the manuscript critically for important intellectual content, approved the final version for submission, and agrees to be accountable for all aspects of the work.

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Data Availability

The non-identifying aggregate data and supporting materials generated and analysed during the current study are included in this article and its supplementary information files. Raw farm identifiers, identifiable interview transcripts, and documentary validation records are not publicly available because disclosure could compromise participant confidentiality and reveal commercially sensitive farm-level information. Additional non-identifying data may be available from the corresponding author upon reasonable request, subject to applicable confidentiality and data-protection restrictions.

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Figures

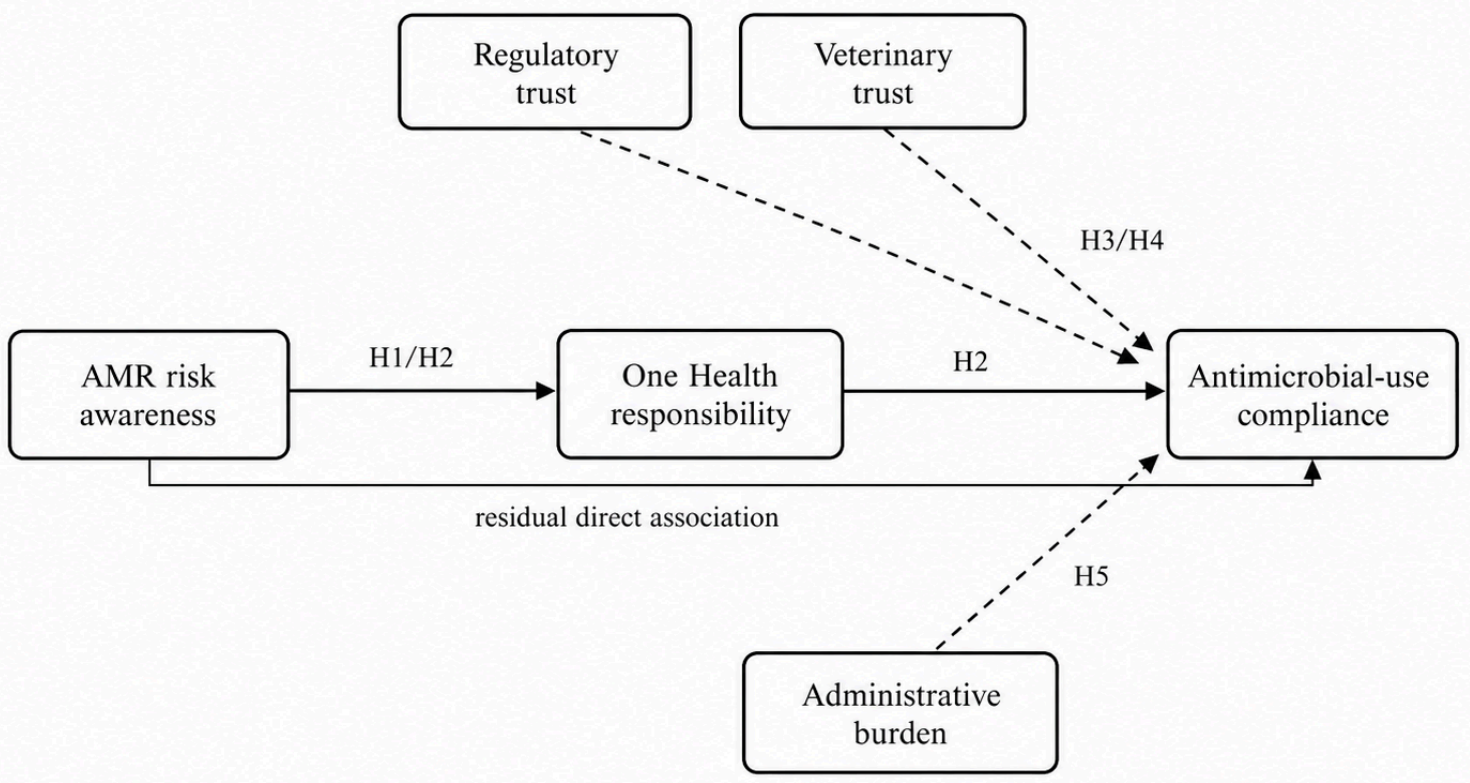


Figure 1

Theoretical model of AMR risk awareness, One Health responsibility, trust, administrative burden, and antimicrobial-use compliance.

Supplementary Files

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