Original Research Article

Phage therapy adoption in ruminant farming: A mediated model of environmental concern, policy pressure, and AMR awareness

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Abstract: Antimicrobial resistance (AMR) will harm global ruminants production but phage therapy use is hardly adopted. This study builds and empirically tests a mediation model where farmer AMR awareness serves as a mediator of the impacts of environmental concern, policy pressure, and technology perception on adoption intention. Using survey data from 342 ruminant farmers in four Chinese provinces (2025-2026) and Structural Equation Modeling results indicate that environmental concern has the largest direct impact (β=0. 462, $p < 0.001$), with AMR awareness mediating 34.7% of its overall effect. And the policy pressure (β=0.318), the technology perception (β=0.247), all is also effect on the adoption. Model is responsible for 54.7% of the variance in adoption intention. It can be found that awareness about how AMR is risky is a very important gate for phage therapy in small ruminants.
Keywords: bacteriophage; antimicrobial resistance; ruminants farming; structural equation modeling; technology adoption

1. Introduction

Antimicrobial resistance has become a silent pandemic. In livestock, approximately 70% of global antibiotic consumption occurs in food animal production, and resistance rates have tripled since 2000. Small ruminants—Ruminants and goats—Are disproportionately neglected in AMR surveillance and intervention research. A 2025 systematic review covering 50 studies across six continents reported AMR prevalence from 0.8% to 100% in ruminant respiratory pathogens, with common resistance to tetracyclines, macrolides, and beta-lactams[1].

Phage therapy—Using bacterial viruses to lyse specific pathogens—Offers a scientifically viable alternative. Recent ovine studies confirm both prophylactic and therapeutic effects of farm-isolated bacteriophages against Escherichia coli-induced lamb diarrhea[2]. In a mastitis mouse model, a broad-spectrum phage cocktail achieved efficacy comparable to antibiotics with reduced proinflammatory cytokines[3]. Despite these advances, adoption of phage therapy in ruminants farming remains marginal, and the behavioral drivers of farmer uptake are virtually unstudied.

This paper asks: What matters for farmers' intentions to use ruminants' phage therapy, and does awareness of AMR mediate it? We combine Technology Acceptance Model and Institutional Theory to give us a mediation framework. Using the primary survey data(N=342) from main ruminants provinces in China, we estimate SEM to measure direct and indirect effects. The threefold contribution: First, empirical focus on small ruminants. Second, specifying AMR awareness as a mediator of the effect. Third, policy-relevant evidence from China's major ruminants-producing provinces, where the National Action Plan for Veterinary Antimicrobial Use Reduction (2021–2025) is being evaluated under the 15th Five-Year Plan (2026–2030).

2. Literature review and hypotheses

2.1. AMR burden and phage therapy in ruminants

AMR in ruminants comes from using sub-therapeutic antibiotics for growth and disease prevention in ruminants. China is estimated to produce around 97,000 tons of antibiotics per year for use in livestock and over 40% of the antibiotics produced are for use in animal agriculture. The Ministry of Agriculture and Rural Affairs carried out around 3700 supervision batches in 2025 and got over 99% compliance, however the marginal productivity of antimicrobial input has reached zero. Worldwide phage therapy market, USD 55.25M (2024) & USD 189M (2031), with CAGR 19.3% (2031). Phage feed additives specifically are forecast to grow from USD 613 million (2024) to USD 1.91 billion by 2033[4]. In 2025, France-based Phagos secured USD 30 million Series A funding for livestock phage deployment, underscoring commercial momentum.

2.2. Theoretical framework and hypotheses

We posit that adoption intention (AI) is directly influenced by three antecedents: Environmental concern (EC), policy pressure (PP), and technology perception (TP). Environmental concern reflects farmers' ecological values; policy pressure captures perceived regulatory signals; technology perception encompasses usefulness and ease-of-use judgments. Moreover, farmer awareness of AMR risks (AA) functions as a mediator: External drivers must be cognitively processed through risk recognition to translate into adoption intentions.

Hypotheses:

H1: EC → AI positive direct effect.

H2: PP → AI positive direct effect.

H3: TP → AI positive direct effect.

H4: AA mediates EC→AI, PP→AI, and TP→AI.

Control variables: Farm size, age, education, flock health status, veterinary access.

3. Methodology

3.1. Sampling and data collection

A cross-sectional survey was conducted September 2025–February 2026 in four provinces: Inner Mongolia (extensive pastoral), Xinjiang (agro-pastoral), Hebei (intensive feedlot), and Sichuan (smallholder mixed). Multistage stratified random sampling selected 450 ruminants farming operations; 342 valid responses (76.0% response rate). Farm size distribution: Small (50–199 head, 41.2%), medium (200–499, 34.5%), large (500+, 24.3%). Mean farming experience 12.7 years; 67.8% primary decision-makers.

3.2. Measures

All constructs measured on 7-point Likert scales (1=strongly disagree to 7=strongly agree) with items adapted from validated technology adoption and environmental psychology instruments. Reliability and validity statistics are presented in **Table 1**.

Table 1. Construct reliability and validity.

Construct	Items	Cronbach's α	CR	AVE
Environmental Concern (EC)	4	0.874	0.881	0.650
Policy Pressure (PP)	4	0.839	0.846	0.579
Technology Perception (TP)	5	0.902	0.907	0.663
AMR Awareness (AA)	5	0.891	0.895	0.631
Adoption Intention (AI)	4	0.913	0.917	0.734

Note: CR=composite reliability, AVE=average variance extracted.

3.3. Analytical strategy and model specification

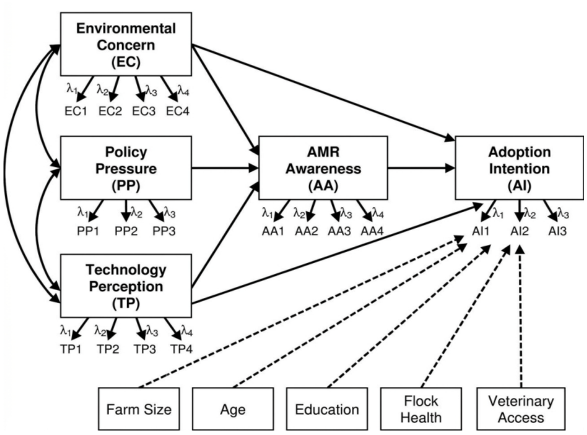

Figure 1. Conceptual mediation model.

We used confirmatory factor analysis (CFA) and structural equation modeling (SEM) with maximum likelihood estimation in AMOS 28.0. Mediation tested via bias-corrected bootstrapping (5,000 resamples). Model fit criteria: $\chi^2/df < 3.0$, CFI/TLI > 0.90, RMSEA < 0.08, SRMR < 0.08.

4. Results

4.1. Descriptive statistics and correlations

Adoption intention mean = 5.38 (SD=1.14), indicating moderately positive inclination. AMR awareness mean = 4.87 (SD=1.32). All correlations positive and significant ($p<0.01$), with AI most strongly correlated with EC (r=0.58) and AA (r=0.54). VIFs ranged 1.37–2.18, no multicollinearity.

Table 2. Means, standard deviations, and correlations.

M	SD	1	2	3	4	5
AI	5.38	1.14	-0.857			
AA	4.87	1.32	0.54**	-0.794		
EC	5.21	1.23	0.58**	0.55**	-0.806	
PP	4.76	1.45	0.49**	0.48**	0.53**	-0.761
TP	4.51	1.38	0.42**	0.44**	0.48**	0.51**

Note: Diagonal parentheses = square root of AVE. p*<0.01.

4.2. Measurement and structural models

CFA indicated acceptable fit: $\chi^2(265)=458.73$, $\chi^2/df=1.73$, CFI=0.959, TLI=0.952, RMSEA=0.046, SRMR=0.041. All factor loadings >0.65. Discriminant validity confirmed (AVE square roots > inter-construct correlations).

Structural model fit: $\chi^2(279)=502.19$, $\chi^2/df=1.80$, CFI=0.952, TLI=0.944, RMSEA=0.048, SRMR=0.045. **Table 3** reports standardized direct effects.

Table 3. Standardized direct effects.

Path	β	SE	t	p	95% CI
EC → AI	0.462	0.058	7.97	<0.001	[0.348, 0.576]
PP → AI	0.318	0.062	5.13	<0.001	[0.196, 0.440]
TP → AI	0.247	0.059	4.19	<0.001	[0.131, 0.363]
EC → AA	0.354	0.062	5.71	<0.001	[0.232, 0.476]
PP → AA	0.296	0.064	4.63	<0.001	[0.171, 0.421]
TP → AA	0.285	0.060	4.75	<0.001	[0.167, 0.403]
AA → AI	0.281	0.055	5.11	<0.001	[0.173, 0.389]

$R^2(AI)=0.547$, $R^2(AA)=0.462$.

4.3. Mediation effects (H4)

Table 4 shows indirect effects via AA are all significant ($p<0.01$). Mediation proportions: EC→AI (34.7%), PP→AI (20.7%), TP→AI (24.5%). Partial mediation supported.

Table 4. Direct, indirect, and total effects.

Path	Direct	Indirect (via AA)	Total	Mediation %
EC → AI	0.462	0.099	0.561	34.7%
PP → AI	0.318	0.083	0.401	20.7%
TP → AI	0.247	0.080	0.327	24.5%

All indirect effects $p<0.01$, bootstrap 95% CI excludes zero.

Among controls, farm size (β=0.112, $p<0.05$), education (β=0.089, $p<0.05$), veterinary access (β=0.157, $p<0.01$) positively predict AI; flock health status (β=-0.076, $p<0.05$) indicates worse health increases adoption intention.

Robustness checks: Harman's single-factor test showed first factor explaining 28.6% variance (<50%), common method bias unlikely. Alternative model comparisons confirmed partial mediation superior.

5. Discussion

This study results in 3 main outcomes. First, environmental concern is the largest predictor of phage therapy adoption intention (β=0.462). Ruminants farmers on grasslands directly observing soil degradation and water contamination from antimicrobial runoff. Eco framings > techno-economics. Second, policy pressure (β=0.318) impacts adoption, like China's tightening on antimicrobial reduction. However, only 36% of farmers consult licensed veterinarians; most rely on informal drugstore vendors[5]. Improving formal veterinary care is needed to get the policy signals to producers. Third, the AMR awareness mediating 20 - 35% of the effects of the antecedents, confirming the cognitive gateway hypothesis. Farmers who internalize AMR as a real production risk are more apt to take up phage therapy, even if there is no strong outside push.

The mediation finding aligns with successful educational programs such as the UK's RUMA Agriculture initiative, which achieved a 57% reduction in livestock antibiotic use through voluntary producer awareness campaigns[6]. As China moves past its 2021-2025 Reduction Action Plan to the 15th Five-Year Plan (2026-2030), integrating AMR awareness training with regulatory enforcement and technology demonstrations.

Practical implications: (1) Educate farmers in how to make explicit connections between AMR and decreased flock productivity/economic loss as opposed to the vague One Health. (2) Environmental messaging-0phage therapy as ecological stewardship-to use existing concerns to our advantage. (3) Veterinary service coverage expansion in ruminants regions; mobile vet units and telemedicine for bridging.

Limitations: Cross-sectional design has limited causal inference, intention is measured as opposed to actual behavior; the sample comes from four Chinese provinces and may not generalize to other ruminants systems (e.g. Africa, South Asia). The next longterm, cross-cultural studies need to bedone for actual adoptions and costs of doing it on a larger scale.

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