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Economic assessment of an intervention strategy to reduce antimicrobial usage in small-scale chicken farms in Vietnam

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ABSTRACT

Antimicrobials are a core aspect of most livestock production systems, especially in low-and middle-income countries. They underpin the efficient use of scarce feed resources and stabilize returns on capital and labor inputs. Antimicrobial use (AMU) contributes to the production of healthy animals, yet AMU in livestock is linked to antimicrobial resistance (AMR) in animals, humans and the environment.

The Vietnamese Platform for Antimicrobial Reduction in Chicken Production was implemented during 2016–2019 and was one of Southeast Asia's first interventions focused on AMU reductions in livestock production. The project targeted small-scale commercial poultry farms in the Mekong Delta region of Vietnam using a "randomized before-and-after controlled" study design. It provided farmers with a locally adapted support service (farmer training plan, advisory visits, biosecurity, and antimicrobial replacement products) to help them reduce their reliance on antimicrobials. A partial budget analysis was performed comparing the control group (status-quo) and intervention group (alternative). The median net farm-level benefit of the intervention strategies with the project's support was VND 6.78 million (interquartile range (IR) VND -71.9–89 million) per farm. Without project support the benefit was reduced to VND 5.1 million (IR VND -69.1–87.2 million) to VND 5.3 million (IR -VND 68.9–87.5 million) depending on the antimicrobial alternative product used. At the project level with a focus on AMU and its reduction, subsequently influence on the resistance reduction, our results showed that achieving resistance reduction benefits with the current knowledge and technologies required investment of at least VND 9.1 million (US$ 395.10) per farm during the project's lifetime. The results highlight the positive net profit for the majority of enrolled farms and a reasonable investments from the project. The recommendation focuses on the implementation of policies on financial support, legislation, and information as potential solutions to facilitate the application of intervention strategies to reduce AMU in poultry production.

1. Introduction

Antimicrobial use (AMU) in animal production is recognized to be significant contributor to the global antimicrobial resistance (AMR) emergency [1]. In particular, levels of AMU in animal production in low- and middle-income countries (LMICs) are particularly high [2] and are expected to further increase over the coming years due to the intensification of animal production and increased demand for animal protein [1,3,4]. However, judicious use of antimicrobials remains an essential tool for sustainable animal production. A case study in Indonesia on small to medium commercial broiler production farms highlighted the economic advantage of using antimicrobials in the broiler resulting in increased productivity and healthier chickens [5]. A strong relationship exists between AMU and the perceived risk of disease in flocks. Excessive AMU is strongly linked to farmers' lack of knowledge, as well as a high incidence of disease and mortality partly due to poor biosecurity and husbandry practices [6]. In addition, the choice of specific antimicrobials is poorly targeted to disease. Data from the region suggests that

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three-quarters of disease incidents in poultry would not be resolved by antimicrobials [7]. Vietnam is regarded as a hotspot of antimicrobial consumption in Southeast Asia because of its high levels of aquaculture, pig and poultry production [4]. In particular, Vietnamese poultry farmers use large amounts of antimicrobials to raise poultry. A recent study showed that 323.4 (SEM ±11.3) mg of antimicrobial compounds were used to produce one meat chicken [8,9]. Prices of antimicrobials in livestock production are very low. The average cost of one Animal Daily Dose (per kilogram of live animal) (ADD_{kg}) is 0.54 cents of 1 US$ with a range of 0.07 to 1.39 cents of 1 US$ [10] and an insignificant aspect of the variable costs of production (1.9% interquartile range 0.7–3.6 [11]). The antimicrobials used would indicate farmers perceive them to be a relatively low-cost means of risk management in production systems prone to disease.

It is assumed that, in chicken production, overall reductions in AMU are possible without negative consequences [12]. However, a study in Indonesian broiler chickens reported that reductions in AMU resulted in increased production costs and higher mortality rates [5]. Changes in practices including improved biosecurity, targeted vaccination, and overall better management may result in overall reductions of disease and AMU. However, the introduction of improvements in disease control implies a cost (capital, variable, and labor) and may have an impact on disease, performance and AMR. Initiatives to curb AMU in animal production are currently being discussed and tested in many LMICs (as well as high-income countries). For example, a three-zone biosecurity model, which splits a farm into three distinct areas based on biosecurity risks to prevent and control disease on farms, has been tested in Indonesian broiler and layer farms [13]. A trial investigating an antimicrobial replacement (nanosilver) in pig feeds in small-scale pig farms was conducted in Vietnam. The trial result showed that substituting antimicrobials in feed with nanosilver were not different in average daily gain and antimicrobial resistance profile of *E.coli* between the control and intervention groups [14].

The ViParc project ('Vietnamese Platform for Antimicrobial Reduction in Chicken Production) was an intervention implemented during 2016–2019 focused on AMU reduction in small-scale poultry farms in the Mekong Delta region. The intervention was designed as a "randomized before-and-after controlled" study. It provided farmers with on-going veterinary support service to help them reduce their reliance on antimicrobials [15]. The intervention resulted in 66% quantitative reductions in antimicrobials used and a more modest (−10.7%) but measurable reduction in antimicrobial resistance gene content (in relation to 16S rRNA) [16,17]. However, these small-scale production systems are characterized by a high turnover (i.e. lots of farmers enter and leave the business) [11] and economic impacts (positive and negative) of such interventions are unknown.

The aims of this study are: (a) to characterize the cost structure of small-scale chicken farms enrolled in a veterinary intervention; (b) to determine the additional costs and benefits of the intervention at farm level; and (c) to estimate the cost-benefit at project level. The final aim is to propose acceptable scaled-up intervention strategies with a high likelihood of being taken up by poultry farmers.

2. Material and methods

2.1. The ViParc trial

The ViParc trial was conducted in Cao Lanh and Thap Muoi districts, Dong Thap province (Mekong Delta, Vietnam). The intervention consisted of two phases: a "baseline phase" (October 2016–April 2018) followed by an "intervention phase" (May 2018 to November 2019). The full description of the baseline and intervention phases and farm selection criteria (i.e. farm size, location, production purpose) can be found elsewhere [11,15,16]. In short, we selected the farm with >100 chicken per flock in selected districts of Dong Thap province. Contradictory to household consumption, chickens were raised in these farms for commercial purposes. During the baseline phase of the study, routine productivity data was collected from enrolled farms without providing any advice/interpretation from the research team. At the beginning of the intervention phase, we randomly allocated registered farms to either the intervention or control group. All intervention farms received support, consisting of (a) farmer training program where farmers were formally trained on good farming practices, prevention and control of infectious diseases, and waste management (six modules in total); (b) regular and scheduled visits by a veterinary professional to provide advice on overall husbandry practices (biosecurity, hygiene, vaccination, brooding practices) and detailed plans for improvements (four times per cycle); (c) the supply of antimicrobial replacement, which was either an essential oil-based (Product A) or a yeast fraction-based product (Product B); and (d) improving on-farm biosecurity by investment on a biosecurity station.

2.2. Data collection

Farmers were provided with purposefully designed diaries for data collection. They were requested to keep weekly records of all relevant data from day-old until slaughter age. The data recorded included costs associated with feed, antimicrobials, other health-related products, other husbandry-related costs, day-off chicks, as well as information on disease, mortality, vaccination (types of vaccines, schedules, etc.). Farmers were asked to keep the packages of all products used for the flock in a dedicated container. Researchers visited study farms four times during each production cycle (1st, 7th, 18th, and 25th week) to identify all products used and review data collected by the farmer. These data were transferred onto a questionnaire and then uploaded to a central database using a web application for further analysis.

2.3. Data analyses

We assessed the baseline (i.e. non-intervention) costs of production followed by an economic analysis of the intervention using partial budget and cost-benefit analytic approaches. The cost structure over the production cycle for intervention farms was performed using the framework described by Bao et al. [11]. In short, the sum of all costs incurred in procuring and raising the flocks was computed as input data, while output data consisted of the revenues derived from the sale of chickens. We calculated the difference between inputs and outputs for each flock produced, excluding labor costs. Costs and revenues were expressed "per chicken sold" at the end of the production cycle. This analysis uses data from all the farms that entered the "intervention phase". Farms that dropped out during the study period (i.e. uncompleted data for a full cycle) were excluded from the analyses.

2.3.1. Partial budget analysis (PBA) at farm level

An economic assessment based on estimating the gross margin (output value minus variable costs) of the batches of chickens raised was performed with data from the study. The marginal costs and benefits were examined using a partial budge analysis (PBA) framework before and after the intervention as proposed by other authors [18,19], modified and adapted to the study context. Partial budget analysis (PBA) is commonly used to evaluate short-term and small changes in a production system, enterprise, or organization. The costs and the benefits of a change are estimated and compared to indicate whether the change is worthwhile [18]. Benefit-cost analysis (BCA) is used for more significant changes that spread benefits and costs over time. It uses the same principles of assessing marginal cost and benefit changes and then applies discounting to allow comparison of costs and benefits that occur in different years [18]. PBA and BCA techniques help test the viability and feasibility of a new strategy regarding financial return [18] or livelihood and overall well-being [20]. PBA and BCA are interested in four essential items: new costs, revenue foregone, costs saved, and new revenue.

The analysis compares the "*status quo*" scenario with no intervention strategies (baseline phase) to the "*alternative scenario*" where intervention strategies were applied (intervention phase) in each farm. The components used in partial budget analysis at the farm level included additional revenue, foregone revenue, additional costs, and saved costs. To access change in two scenarios, we estimated the difference between the sum of the benefits (*costs saved* + *new revenue*) and the sum of the costs (*new costs* + *revenue foregone*).

Additional costs (AC_F) at the farm level, which were not included in the "status quo" scenario, represented extra costs associated with the intervention strategies (alternative scenario). It includes the cost of advisory visit ($C_{advisory}$), cost of investment in biosecurity station (C_{biokit}) installed and maintained during the cycle, and cost of alternative product used instead of antibiotic($C_{alternative}$). To clarify the calculation, we distinguished two cases where the project supports (Case 1) or does not support (Case 2) the investment of some additional costs for farmers. In Case 1, the project supported farmers for the cost of advisory visits ($C_{advisory}$), the cost of investment in biosecurity station ($B_{purchase}$), and the cost of antimicrobial replacement products ($C_{alternative}$). As the volume and price of two antimicrobial replacement products differed, two formulas and two separate results (for products A and B) were also computed.

Saved costs (*SC_F*) at the farm level, which was represented in the "status quo" scenario, could be avoided in the "alternative scenario". It included the difference in the cost of antimicrobial usage per animal in two scenarios.

Additional revenue (*AR_F*) at farm level represented the revenue gained from applying intervention strategies which was not present in the baseline stage. It included the difference in revenue between selling healthy, safe chicken and selling regular chicken produced in everyday practice ($R_{chicken}$).

Foregone revenue (*FR_F*) at farm level represented the revenue gained from the "status quo" scenario and disappeared in the "alternative scenario". It included time spent by farmers on the training ($T_{training}$).

The net benefit at the farm level (*NB_F*) (additional benefits minus additional costs) of the change in the application of intervention strategy observed in the "alternative scenario" compared to the "status quo" scenario was calculated throughout one cycle as follows:

$$\mathrm{NB\_F} = (\mathrm{SC\_F} + \mathrm{AR\_F}) - (\mathrm{AC\_F} + \mathrm{FR\_F})$$

The detailed formulas and variables of each component are described in Table 1.

We included only the farms enrolled both in the baseline and intervention phases for PBA at the farm level. Those farms were considered professional enterprises. The economic analysis based on the data generated from those farms could help us understand the profitability of this poultry production business and avoid the bias caused by seasonal farmers who raise one or two flock cycles per year.

2.3.2. *Assumptions used in the partial budget analysis at the farm level*

We assumed that feed cost mainly influenced the loss due to the reduction of growth of healthy animals while the antimicrobial replacement could partly maintain the chicken performance. In addition, carcasses or sick birds were not sold for commercial purposes. They were used for auto consumption or were destroyed or buried on site.

2.3.3. *Sensitivity analysis for PBA at farm level*

The sensitivity analysis for *NB_F* from intervention strategies was performed by changing the market price of chickens sold. This analysis was performed to understand the variation of these parameters on the *NB_F* associated with the intervention strategy. Three proposed scenarios (S1, S2, and S3) were considered. In those three scenarios, the market price of chicken sold increased by 20%, 50%, and 100%, respectively, compared with the normal price observed in the intervention phase (S0). Those scenarios were based on the hypothesis that farmers would get higher income from selling antibiotic-free products in

Table 1

Formula and variables used in the calculation of net benefit from intervention strategies reducing antimicrobial usage at the farm level.

Formula and variables
Additional costs $(\mathrm{Add.cost\_F}) = C_{advisory} + C_{biokit} + C_{alternative}$
$+C_{advisory} = (D_{advisory} {}^{*} S_{day-vet})$
$+C_{biokit} = (B_{purchase} + B_{maitenant} + rC_{investissment} {}^{*} N_2)$
$+C_{alternative} = (V_{alternativeA(B)} {}^{*} K_2 {}^{*} P_{alternative})$
$C_{advisory}$: Cost of advisory visits made by professional veterinary
C_{biokit}: Cost of investment in biosecurity station
$C_{alternative}$: Cost of alternative product used instead of antibiotic
$D_{advisory}$:Number of advisory visits
$S_{day-vet}$: Daily veterinarian's salary
$B_{purchase}$: Price of biosecurity methods purchased per farm
$B_{maintenance}$: Price of maintaining biosecurity methods during cycle
$rC_{investissment}$: Differences in investment cost focus on biosecurity on farm
N_2: Total number of animals in one cycle ("alternative" scenario)
K_2: Total number of animals sold in one cycle ("alternative" scenario)
$V_{alternative}$: Volume of alternative product (A or B) used for one chicken during cycle
$+ V_{productA} = 0.225\ \text{liter water/day/chicken} {}^{*} 3\ \text{days/week} {}^{*} 10\ \text{week/cycle} {}^{*} \frac{5\ \text{liter water}}{1\ \text{ml product}}$
$+ V_{productB} = 0.225\ \text{liter water/day/chicken} {}^{*} 3\ \text{days/week} {}^{*} n_{week} {}^{*} \frac{5\ \text{liter water}}{1\ \text{ml product}}$
0.225: Average water consumption per chicken (in liters)
n_{week}: Number of weeks raising a flock
$P_{alternative}$: Price of alternative product (in g or ml)
Saved costs $= rC_{Ab\_flock} = C_{Ab-animal1} {}^{*} N_1 - C_{Ab-animal2} {}^{*} N_2$
rC_{Ab_flock}: Difference in cost of antimicrobial usage per animal
$C_{Ab-animal1(2)}$: Cost of antimicrobial usage per animal in "status quo" ("alternative") scenario
N_1 Total number of animals in one cycle ("status quo" scenario)
Additional revenue $(Add.rev\_F) = R\_chicken = R\_chick2 {}^{*} \alpha {}^{*} K\_2 - R\_chick1 {}^{*} K\_1$
$R_{chicken}$: Revenue from selling chicken
$R_{chick1(2)}$: Revenue from selling one chicken in the "status quo" (the "alternative") scenario
α: Percentage of increase in price
K_1: Total number of animals sold in the "status quo" scenario
Foregone revenue $(For.rev\_F) = R_{chicken\_died}$
$R_{chicken\_died}$: Revenue from selling illness or dead chicken

the future.

2.3.4. Benefit-cost analysis at project level

For this analysis, we detailed and compared the intervention's additional costs (project costs) and benefits. The latter element was subdivided into total net benefit at the farm level and antimicrobial resistance reduction benefit. The net benefit for the project was the benefits of the intervention minus the additional costs. The overall impact of the project was on AMU and its reduction. We assumed that a reduced AMU also reduced AMR. Our study did not focus on quantifying the benefit of a lower AMR but the benefit of a lower AMU calculated through an economic formula. The implication of the project is an economic shift for farmers. Therefore, the term "antimicrobial resistance reduction benefit" was used in our formula.

Benefit-cost analysis at the project level was performed using the following formulas

$$\mathrm{NBPH} = \mathrm{Tot\_NB\_F} + \mathrm{AMRRB} - \mathrm{PC}$$

Where

$$Tot\_NB\_F = NB\_F{*}n{*}Cy{*}ny$$

And

$$PC = C_{tra} + C_{app}$$

In which.

NBPH: net benefit for the project

Tot_NB_F: total net benefit at farm level

PC: project cost

NB_F: net benefit at the farm level

n: number of farms enrolled in the project

Cy: number of production cycles per farm per year $= \frac{52 \text{ weeks per year}}{17.5 \text{ weeks per cycle}}$

ny: number of years implementing the project

AMRRB: antimicrobial resistance reduction benefit - benefit from AMU reduction

C_tra: part of project cost, cost of organizing training for farmer

C_app: part of project cost, cost of developing auditing tool for farm evaluation

Other project costs considered in previous analyses (alternative products, a biosecurity station), are excluded at this stage. The remaining additional costs at the project level included organizing training for farmers (C_tra), subdivided into the salary for speakers during training courses and the cost of course development. Another additional cost was the development of an auditing tool (*C_app*) that was used to evaluate progress in each visited farm.

In our hypothesis, the NBPH should be equal to or bigger than zero. Therefore, in the current circumstance and chicken production, AMRRB should meet the following criteria:

$$\mathrm{AMRRB} \geq \mathrm{PC} - \mathrm{Tot\_NB\_F}$$

All statistical analyses were performed using R software [21]. Two calculation frameworks of calculation *NB_F*, which included functions and formulas, were developed separately in the R environment for the deterministic and stochastic models. The calculation used each parameter's mean or unique values for the deterministic model. In the stochastic model, each parameter's mode, min, and max values were used with a Monte Carlo procedure to overcome the uncertainty over the data. The probability distribution of the *NB_F* was obtained by re-sampling 1000 values of parameters from their respective assumed probability distribution, using the Latin Hypercube sampling procedure through package called "lhs" [22].

2.4. Ethics considerations

This study was granted ethics approval by the Oxford Tropical Research Ethics Committee (OxtTREC) (Ref. 5121/16) and by the local authorities (People's Committee of Dong Thap province).

3. Results

3.1. Description of study flocks

A total of 102 farms were enrolled and 219 flock production cycles were investigated to collect data on the cost structure during the baseline phase [16]. During the intervention phase, we collected financial data from 89 flocks (39 farms). Among them, data from 77 flocks (31 farms) were collected from the intervention arm, and 12 flocks (4 farms) from the control arm. Their full description can be found in Table 2. In total, 296 flocks with relevant economic data were used to estimate the four elements of the partial budget and benefit-cost analysis.

3.2. Cost structure over the flock production cycle during the intervention phase

For each flock cycle, the financial costs (in 1000 s VND) incurred in raising one chicken from day-old to slaughter, percentage of the components in cost (feed, day-old chicks (DOCs), health supporting products (i.e., vitamins, vaccines, antimicrobials) and other costs) and the revenue obtained. Results expressed per chicken sold are displayed in Table 3. The median revenue received per unit of chicken sold was 115.8 thousand VND [Inter-quartile range (IQR) 100.7–130.1]. Feed costs, including both commercial and locally sourced feed, constituted the highest proportion of the financial cost, with a median of 72.3% [IQR 64.6–76.6], followed by DOCs (median 17.1% [IQR 13.9–20.8]). On the other hand, antimicrobials represented the lowest proportion, with a median of 0.3% [IQR 0.1–0.9], among the included expenses.

Table 2

Description of critical variables related to small-scale commercial chicken flocks enrolled in the intervention arm (Dong Thap province, Mekong Delta, Vietnam).

	Variable and level	Median [IQR] or number (%)	Rang (Min.-Max.)
Farms (*n* = 31)	District		
	Cao Lanh	17 (54.8)	
	Thap Muoi	14 (45.2)	
	Male farm owner	27 (87.1)	
	Farm owner's age (years)	49 [40–56]	24–72
	No. of staff (incl. owner)	2 [2–2]	1–2
	Experience in commercial poultry farming (year)	2 [1.5–3]	1–10
	Education achievement of owner (%)	13 (41.9)	
	Primary school	11 (35.5)	
	Secondary school	5 (16.1)	
	High school	2 (6.5)	
	University or higher		
Flocks (*n* = 77)	Flock size per cycle (No. heads)	351 [153–509]	100–1020
	Duration of cycle (weeks)	17 [16–19]	9–24
	Bodyweight of chicken at sale (kg)	1.6 [1.4–1.7]	1.1–2.6
	Feed type		
	Commercial feed only	70 (90.1)	
	Commercial feed & locally sourced feed	7 (9.1)	
	Antimicrobial replacement used	28 (36.4)	
	Product A (essential oil)	43 (55.8)	
	Product B (yeast extract)	6 (7.8)	
	Not used		
	>1 flock raised on the farm at the same time	51 (66.2)	
	Flock raised on farms with non-chicken species*	75 (97.4)	

[*] Including ducks, Muscovy ducks, quails, pigs, goats, and cattle.

Table 3
Financial costs and revenue obtained per chicken unit (in VND) (values were estimated from the 77 flocks enrolled in the intervention phase).

Item	Median (x 1000 s VND)	IQR (x 1000 s VND)	Median (%)	IQR (%)
Feed (commercial and other)			72.3	64.6–76.6
DOCs			17.1	13.9–20.8
Non-antimicrobials health-supporting products (vitamins, mineral, additives)			3.0	1.7–4.4
Vaccines			2.3	1.7–3.5
Antimicrobials			0.3	0.1–0.9
Other costs (equipment, litter, electricity and disinfectants)			2.4	1.5–4.2
Total cost	69.8	52.4–83.4		
Revenue	115.8	100.7–130.1		

3.3. Partial analysis of intervention strategies at the farm level

3.3.1. Deterministic model at the farm level

The financial data on the cost of the intervention and the revenue obtained from selling chickens at the farm level are summarized in Table 3 and Supplementary Table 1. The average cost of antimicrobials decreased from 1100 VND per flock cycle in the baseline phase to 500 VND per flock cycle during the intervention phase.

The result of the partial budget analysis of intervention strategies at the farm level using a deterministic model is presented in Table 4. The net benefit was negative either with (case 1) or without support from the project (case 2) on additional costs. In case 1, the net benefit generated from the model is −0.06 million. In case 2, the mean benefits of farms using alternative products A and B were − 1.03 and − 0.88 million VND, respectively. The detailed cost composition of the intervention strategy is described in Supplementary Table 2. Despite the type of alternative products, the advisory visits cost remained the best proposition in terms of monetary value, followed by the implementation of a biosecurity station.

3.3.2. Stochastic model and sensitivity analysis of partial budget analysis at the farm level

The detail of animal production parameters used as input data for the stochastic model is presented in Supplementary Table 3. The point of partial budget analysis sub-divided into four components was shown in Table 5, which including also the estimation of net benefit at the farm level. The median net benefit (NB) value was positive in both case 1 (6.7 million VND) and case 2 (5.1 million VND when using alternative product A and 5.3 million VND when using alternative product B). The distribution of the net benefit in stochastic model highlighted the positive net profit for more than half of the enrolled farms in Scenario 0 and higher in three theoretical scenario (Supplementary Figs. 1, 2). However, the 95% CI encompassed 0, indicating potential harm or uncertainty in profitability. The median NB increased progressively in three theoretical scenarios as additional revenue increased, but their 95% CI still contained negative values.

3.4. Benefit-cost analysis of intervention at the project level

The minimum antimicrobial resistance reduction benefits per three-year project (1035 and 896 million VND) were 10.6 and 9.2 times higher than the project cost (approximately 97,4 million VND) for intervention strategies. The analysis showed that achieving resistance reduction benefits under the current knowledge and technologies requires the investment of at least 9.1*10ˆ6 VND (395.1 USD) per each enrolled farm during the project's time (annually investment 131.7 USD) (Table 6).

4. Discussion

Our study provides an assessment of the economic impact of an antimicrobial-reducing intervention on commercial small-scale farms raising slow-growth native chickens in Vietnam. These results add to economic assessments of AMU-reducing interventions conducted in dairy [23], broiler [24], and pig [25–27] in other countries. Our intervention strategy showed a positive net profit for more than half of enrolled farms through simulation model. This observation was strictly gathered from pre- and post-intervention measurements in the same farms. Our intervention used a holistic approach that included antimicrobial replacements, biosecurity improvements, and education. Scientific evidence demonstrated that interventions involving a combination of various strategies to influence behavior tend to generally achieve a higher rate of success compared to interventions relying on single strategies [24,28].

In Vietnam poultry farming the use of antimicrobials is closely related to suboptimal animal husbandry conditions including poor hygiene and biosecurity. Given the low cost of antimicrobials in Vietnam, they are often used to compensate for inadequate implementation of other more demanding husbandry practices (i.e. good biosecurity, cleaning and disinfection, purchase of high-quality day-old-chicks, etc.) and veterinary advice. Data from countries such as China show that antimicrobials act as a low-cost "insurance" against potential disease outbreaks [29].

In Vietnam, a holistic approach was similarly adopted in another intervention study focusing on biosecurity enhancement of chicken farms, including infrastructure improvement, farming conditions and cleaning conditions, and behavioral change. The result showed an almost two-fold decrease in the cost of antibiotics in intervention broiler farms compared to control farms. Additionally, a positive correlation was observed between the adoption of biosecurity and good practices and economic performance. However, a significant distinction between this study and our study is the absence of baseline data for both model and control farms before the intervention [30]. Other interventions, a combination of training in flock vaccination, water management, brooding and grower management, disease management, and structural and operational biosecurity, were carried out in small commercial broiler farms in Indonesia. This involved seven project farms and four control farms over a two-year period. These measures align with those implemented in this study, with the exception that antimicrobial replacement products were not used. The results indicated a 3% increase in the Performance Index on project farms, while a 2.6% decrease was observed on control farms. The economic gain resulting from the adoption of these measures equaled USD 78.00 per 1000 birds, with a minimal investment of just USD 2.00 per 1000 birds [31].

At the project level, the per farm costs associated with the

Table 4
Partial budget analysis result at farm level (x 1000,000 s VND) – deterministic model.

Case	Additional cost A	Additional cost B	Saved cost	Additional revenue	Forgone revenue	Net benefit A	Net benefit B
1	0.11	0.11	0.23	1.48	1.66	−0.06	−0.06
2	1.08	0.93	0.23	1.48	1.66	−1.03	−0.88

1 (2) represents the case with (without) support of the project on additional costs; A and B letters represent the interventions, which were differentiated by the alternative products, while the remaining components, such as training, advisory visit, investment in biosecurity station presented in both cases.

Table 5
Result of 4 components used in partial budget analysis and net benefit estimation at farm level (x 1000,000 s VND) from stochastic model and sensitivity analysis (median [interquartile range]).

	AC_A	AC_B	SC	AR_S0	AR _S1	AR _S2	AR _S3	FR
Case 1	−0.5 [−7.0–4.4]	−0.5 [−7.0–4.4]	−0.2 [−2.4–1.5]	7.8 [−70.5–88.3]	15.3 [−65.9–109.6]	25.6 [−59.6–141.5]	43.9 [−52.0–196.1]	1.5 [0.6–2.2]
Case 2	0.5 [−5.7–5.2]	0.4 [−6.1–4.9]	−0.2 [−2.4–1.6]	7.5 [−67.9–87.6]	14.1 [−62.4–108.2]	25.1 [−56.1–138.7]	42.1 [−46.8–194.5]	1.5 [0.6–2.2]
	NB _A_S0	NB_B_S0	NB_A_S1	NB_B_S1	NB_A_S2	NB_B_S2	NB_A_S3	NB_B_S3
Case 1	6.7 [−71.9–89.0]	6.7 [−71.9–89.0]	14.0 [−67.7–109.3]	14.0 [−67.7–109.3]	24.5 [−61.8–141.9]	24.5 [−61.8–141.9]	42.4 [−54.0–195.6]	42.4 [−54.0–195.6]
Case 2	5.1 [−69.1–87.2]	5.3 [−68.9–87.5]	12.3 [−63.7–107.1]	12.5 [−63.6–107.4]	23.0 [−58.0–139.3]	23.2 [−57.9–139.7]	40.4 [−48.7–193.2]	40.6 [−48.5–193.7]

A and B letters represent the interventions which were differentiated by the alternative products; S0, S1, S2, S3 represent the scenario where market price of chicken sold increase 0%, 20%, 50% and 100%; AC additional cost; SC saved cost; AR additional revenue; FR forgone revenue; NB net benefit.

Table 6
Variables and computed results for benefit-cost analysis at the project level.

Variables	Abbreviation (if any)	Value	Unit
Net benefit at the farm level ([*])	NB_F	−1031(A) −878 (B)	x 1000 s VND
Number of farms enrolled in the project	n	102	Farm
Number of production cycles per farm per year	Cy	2.97	Time
Number of years implementing the project	ny	3	Year
Cost of organizing training for farmer	C_tra	74,400	x 1000 s VND
Cost of developing auditing tool for farm evaluation	C_app	23,000	x 1000 s VND
Total net benefit at farm level	Tot_NB_F	−938,080 (A) −798,873 (B)	x 1000 s VND
Project cost	PC	97,400	x 1000 s VND
Project cost per farm per year		318	x 1000 s VND
Antimicrobial resistance reduction benefit per 3 years project	AMRRB	1035,480 (A) 896,273 (B) 45,020 (A) 38,968 (B)	x 1000 s VND USD

A and B letters represent the interventions which were differentiated by the alternative products.

[*] Result from Table 4, case 2.

intervention was three times lower than the estimated antimicrobial resistance reduction benefit in economics. This gives an indication of the worthwhile nature of the project investment. Further work is needed to quantify the impact of the project intervention on antimicrobial resistance in animals and humans. Antibiotics used in agriculture, especially in livestock production, is a crucial contributor to human in antimicrobial resistance [32–34]. A recent systematic review and meta-analysis showed that the risk reduction of the prevalence of AMR in animals using AMU restriction strategies ranged between 0 and 39% [34]. However, the quantitative contributions to treatment failure remain unclear [23].

At farm level, the benefits of the intervention considerably differed among individual farms. A proportion of farm decided to stop raising chicken due to experienced high mortality and thus negative return on investment which was similar to baseline phase [35]. This could be attributed to factors such as participant engagement or external influences such as fluctuations in the chicken market price. Veterinary advice was provided through a persuasive approach, and the uptake of this advice heavily relied on the farmers' willingness and available resources. In our trial, farmers were initially motivated to participate. However, over time, many realized they needed to spend more resources (working time, investment), but the revenue remained the same as the traders were unwilling to buy their chicken at higher prices even though they were antibiotic residue-free. In fact, during the intervention phase, most farms sold their chickens at prices roughly the same as during the baseline phase. However, during the whole study duration, we observed high short-term price fluctuations. The live chicken market price was reported to display a 40% variation within days [33]. Despite some farmers' efforts to reduce AMU, they sold their chicken at the normal market price (without market reward). Then, depending on the positive (negative) outcome or progress of the application, they will change their decision [34]. Consequently, long-term adherence to intervention strategies might be difficult to achieve, unless there is a market reward for the farmers. A study showed that small-scale farm's adoption of biosecurity measures correlated with household income [35].

The Vietnamese government has issued regulations focusing on antimicrobial prescription and a roadmap from 2020 to 2025 of restricting antibiotic mixing in feed to prevent animal diseases as an essential step in implementing an Antimicrobial Stewardship program [36]. This proactive intervention is an innovative way to help farmers adapt to new circumstances when these regulations are applied. While investment costs in biosecurity and alternative products remain a primary concern for farmers, the long-term benefits of this endeavor are precious. To enhance the effectiveness and sustainability of the intervention, several actions can be taken to increase the selling price of chickens. These may include implementing an effective marketing plan to boost consumer recognition. It has been reported that the consumer preferences tent to shift towards antibiotic-free and organic-labeled meat, and they are willing to pay a premium for safety-labeled chicken [37] or fresh pork [38]. The second potential solution is to involve collaboration among stakeholders across the poultry value chain, including farms, extension organizations, and private sectors. This collaboration can enhance the acceptability and feasibility of implementing minimum biosecurity measures under the close supervision of experienced staff [30]. Cooperative groups or partnerships with pig enterprises are encouraged to engage in the product chain, supported by robust regulations from governmental authorities to ensure the production of antimicrobial use-safe products.

5. Limitations

The cost at the project level did not include the loss due to the withdrawal of farms during the intervention period. The withdrawal of farms could be attributed to the unwillingness to continue chicken raising over time or the loss in previous production cycles, given that small-scale chicken farming is a risky business with revenue on investment that is less than zero in 51% of cases, which was observed in the baseline phase.

6. Conclusion

Our intervention strategy and simualion model analysis resulted on average a positive net profit for the majority of enrolled farms. The project's investment for each enrolled farm to curb AMU is also resonable and feasible. Therefore, we recommend implementing policies that facilitate the implementation of advisory intervention strategies to reduce excessive AMU. Further intervention studies focusing on other farming production could be a new direction to fill the knowledge gaps.

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Author contributions

DBT, NVC, TKB, JCM, JR designed study and developed the protocol. DBT, DHP, NNM contributed to data analyses. DBT, NVC, DHP, MNN, LTTH, JCM and JR contributed to writing up the manuscript. All authors have approved the submitted version of manuscript.

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CRediT authorship contribution statement

Truong Dinh Bao: Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Nguyen Van Cuong:** Conceptualization, Data curation, Methodology, Writing – original draft. **Nguyen Nhu Mai:** Writing – original draft, Writing – review & editing, Formal analysis. **Le Thi Thu Ha:** Writing – original draft, Writing – review & editing. **Doan Hoang Phu:** Formal analysis, Writing – original draft, Writing – review & editing. **Bach Tuan Kiet:** Conceptualization, Data curation, Writing – original draft. **Juan Carrique-Mas:** Conceptualization, Data curation, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing. **Jonathan Rushton:** Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

All authors declare no conflict of interest.

Data availability

Data will be made available on request.

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