The technical and economic impact of veterinary interventions aimed at reducing antimicrobial use on broiler farms*

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ABSTRACT Antimicrobial resistance is a global threat for both human and animal health. One of the main drivers of antimicrobial resistance is inappropriate antimicrobial use in livestock production. The aim of this study was to examine the technical and economic impact of tailor-made interventions, aimed at reducing antimicrobial use in broiler production. Historical (i.e., before intervention) and observational (i.e., after intervention) data were collected at 20 broiler farms. Results indicate that average daily gain and mortality generally increased after intervention, whereas feed conversion and antimicrobial use decreased. Economic performance after interventions was generally higher than before the interventions. Sensitivity analyses on price changes confirm the robustness of the findings.

Key words: broiler production, antimicrobial use, farm-specific interventions, technical and economic farm performance

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INTRODUCTION

The introduction of antimicrobials in the second half of the 20th century has made a significant contribution to animal health and welfare as well as production efficiency (Odonkor and Addo, 2011; Speksnijder et al., 2015b). Within the animal production sector, pig and broiler production are top sectors using antimicrobials (Filippitzi et al., 2014; van Boeckel et al., 2015). Besides therapeutic treatments, antimicrobial agents are used for prophylactic purposes (i.e., disease prevention), metaphylactic purposes (i.e., group treatment when one or more animals of a flock or herd show disease symptoms), and growth promotion (McEwen and Fedorka-Cray, 2002). An important negative consequence of antimicrobial use (**AMU**) is the potential risk for public health as it contributes to the selection and spread of antimicrobial resistance (**AMR**), especially when antimicrobials are used inappropriately (e.g., excessive use or under dosing of antimicrobials). Hence, there is societal and political pressure to reduce AMU. This is also reflected in current legislation in the EU and North America that aims to reduce AMU in food animals, like the introduction of evidence-based therapeutic antimicrobial guidelines as well as banning the use of antimicrobial agents as growth promoters. However, reducing AMU is not straightforward due to the high efficacy of antimicrobials and their relatively low cost (Lhermie et al., 2017). Generally, there is agreement among policy makers and scientists that the use of antimicrobial growth promoters is not necessary since proven management alternatives are available which yield similar economic results (Aarestrup et al., 2010; Maron et al., 2013). Prophylactic use is also considered as overuse since application occurs even when there are no symptoms of disease. However, for metaphylactic and therapeutic use, it is less clear whether the use is justified.

Veterinarians can play an important role in reducing AMU by farmers (Speksnijder et al., 2015a; Currie et al., 2018). Tackling farm-specific problems through tailor-made interventions might therefore be an important tool in reducing (the need for) AMU. Studies in pig production have shown that AMU can be reduced without jeopardizing technical performance (e.g., Postma et al., 2017). However, the farmers' main objection to implement new strategies for further reducing AMU appeared to be mainly financial (Visschers et al., 2015). Hence, there is a need to investigate the economic impact of reducing AMU. Existing studies on the impact of AMU on economic performance have focused on substituting improved management practices, particularly biosecurity measures, for AMU in commercial pig production (Rojo-Gimeno et al., 2016; Postma et al., 2017). The possibilities of reducing AMU in broiler production through the application of tailor-made interventions have not been investigated so far. In addition,

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existing studies did not yet examine the impact of such interventions on technical and economic performance. In the light of the foregoing, the aim of this study was to examine the impact of tailor-made interventions in broiler production, aimed at reducing AMU, on technical and economic performance.

MATERIALS AND METHODS

Data

The data used in this study were collected at 20 broiler farms within the context of an European project regarding AMR by using convenience sampling. The data are from 1 of the 9 European countries included in the framework of the project. Within the consortium, it was agreed to anonymize the countries. The broiler farms in this study were conventional farms with an intended slaughter age lower than 60 D and a growth rate higher than 55 g/d. Farms generally have multiple poultry houses, where each poultry house houses between 10,000 and 40,000 birds and the stocking density is 10 birds or more per square meter. Farmers' participation in the survey used in this study was voluntary. Based on the first farm visit and historical production data of each farm (containing the data of at least 6 different flocks), the type of interventions was defined in a farm-specific action plan aimed at reducing AMU. Based on the interventions described in the action plan, further farm visits were planned to evaluate the interventions and/or to start new interventions (if needed).

For each participating farm, historical data (i.e., before intervention) and observational data (i.e., after intervention) were collected on a flock basis. Data were collected with respect to technical performance, such as average daily gain (**ADG**), feed conversion rate (**FCR**), mortality (**MR**), and AMU. Data on AMU were quantified in a standardized manner by using the treatment incidence (**TI**) as described by Persoons et al. (2012). The TI is defined as the number of animals per 1,000 that are treated daily with one defined daily dose (**DDD$_{\mathbf{VET}}$**). The DDD$_{VET}$ is defined as average maintenance dose per day and per kg chicken of a specific drug (Jensen et al., 2004). The following formula was used to calculate the $TI_{1,000}$ (see equation 1):

$$TI_{1,000} = \frac{total\ amount\ of\ antimicrobial\ adminstered\,(mg)}{DDD_{VET}\,(mg/kg) \cdot number\ of\ days\ at\ risk \cdot \text{kg chicken}} \cdot 1{,}000\ animals\ at\ risk \qquad (1)$$

The number of flocks in both the historical and the observational data differs per farm. Historical data were available for 136 flocks (i.e., an average of 6.8 flock observations per farm) and observational data for 206 flocks (i.e., an average of 10.3 flock observations per farm).

The data were strictly screened by project partners. However, additional screening of technical performance indicated some large deviations within farms (e.g., a FCR higher than 2 or an ADG higher than 80 g/d). These deviations were considered potential outliers (i.e., potential experimental errors). A total of 36 observations with potential outliers and missing data were observed. Thereafter, the project partner that collected the data checked the potential outliers by recalculating the performance indicators based on additional data that were not incorporated in this study. Finally, 13 potential outliers appeared to be correct, 12 potential outliers were corrected, and 11 observations with outliers (9) or missing data (2) were removed. Details with respect to the screening of the data can be found in the Appendix (see Table A.1).

In addition to the data of the intervention farms, similar data from 13 non-intervention broiler farms were collected. These farms are semi-control farms since no specific action plan was developed nor implemented. However, regular veterinary practices have taken place at these farms. The data of these farms were therefore used to compare the results of the intervention farms with the results of non-intervention farms.

Definition of Intervention

Following definitions on intervention in human medicine by Davey et al. (2017), an adapted definition of intervention is any act, fact, or measure on where and why antimicrobial agents are used with the particular aim to reduce (the need for) AMU. Interventions in the present study can focus on the *farmer*, *farm, and animal*. Interventions regarding the farmer are also known as persuasive interventions, which are targeted actions against specific AMU, the review of treatments and rules to omit preventive treatments and to limit to therapeutic indications. These interventions mainly aim at changing the attitude of farmers and convincing farmers to reduce AMU. Interventions aimed at the farm are mainly aimed at farm management, while interventions aimed at the animals are mainly aimed at disease management (i.e., susceptibility of animals to diseases). Both interventions related to the farm and the animals are also known as structural interventions. The type and number of interventions depend on the tailor-made action plan that was established according to the specific problems on the farm, and can therefore vary between farms.

Statistical Tests

Interventions in the present study were based on the individual characteristics of the farm. In addition, the baseline for both AMU and farm performance was different for each farm. Consequently, assessing causal dose–response relations between intervention, AMU, technical farm performance, and economic farm performance was not possible. Statistical tests were therefore limited to the degree of change for each individual farm, and each farm is therefore used as its own control.

The non-parametric Wilcoxon rank-sum test (also known as the Mann–Whitney U test) was used to compare whether 2 independent samples (i.e., historical and observational) of a dependent variable (i.e., either ADG, FCR, MR, AMU, or gross margin) are from populations with the same distribution (Wilcoxon, 1945; Mann and Whitney, 1947). The unbalanced designs and small sample size in the present study are likely to violate the assumptions of the independent samples t-test (Altman and Bland, 1995). The Wilcoxon rank-sum tests were carried out in Stata/SE 15.0 (Stata Statistical Software: Release 15. College Station, TX: StataCorp LLC), which provides the z statistic and corresponding *P*-value. In addition, an estimate of the probability that a random draw from the historical data is larger than a random draw from the intervention data was obtained for each farm and for each variable. This probability was calculated by dividing the Mann–Whitney *U* statistic by a multiplication of both sample sizes.

Effects of intervention might only be visible after a certain lapse of time. The presence of such a lag period was tested by removing the observational data of the technical performance variables one by one (i.e., the first flock from the observational data was removed first; next the second flock was removed, and so on). Results of the Wilcoxon rank-sum tests after removing flock observations from the observational data are presented in the Appendix (see Tables A.2–A.5). Each table shows the results of a separate dependent variable with respect to technical farm performance. The results do not provide clear evidence of a lag period, and all observational data were therefore included in the subsequent analyses.

Economic Impact

The economic impact of on-farm intervention is estimated in 2 different ways. First, by calculating the economic value (**EV**) of changes in technical performance, and second by assessing the impact on the gross margin.

Economic Value of Changes in Technical Performance The EV of the change in single technical performance parameters (including ADG, FCR, and MR) is calculated using the historical and the observational data. The EV of the change in ADG ($\mathbf{EV_{ADG}}$) was estimated in 2 ways. The first way assumed that the cycle duration is constant and computes the change in slaughter weight following a change in ADG (see equation 2).

$$EV_{ADG} = \Delta ADG \cdot CD \cdot ((PP - (FCR \cdot FP)) \cdot 10{,}000\ DO) \qquad (2)$$

where ΔADG is the change in average daily gain when comparing average historical data and the intervention flock under review

CD is the cycle duration, which is an average of the observational data;
PP is the producer price per kilogram meat
FCR is the FCR of the intervention flock under review
FP is the feed price per kilogram feed
DO is the number of day-old chicks at set-up

Within this equation, the change in ADG (compared with the historical average) was multiplied with the cycle duration, in order to calculate the total change in slaughter weight. An increase (decrease) in weight results in a higher (lower) revenue. However, there was also an effect on the feed costs, since a change in feed intake compensates a change in slaughter weight. The change in feed consumption was estimated by multiplying the change in slaughter weight with the FCR. This was multiplied with the feed price to express the change in feed consumption, resulting in the EV of a change in ADG per broiler. For comparison reasons, this was multiplied by 10,000 animals at set-up.

The second way to computing the EV of a change in technical performance assumed a constant slaughter weight while the cycle duration changes with the change in ADG (Gocsik et al., 2013). In that case, the assumption of constant slaughter weight holds (see equation 3).

$$EV_{ADG} = \frac{\left(\frac{365}{\left(\frac{SL-ST}{ADG_{t_i}}\right)+EP} - \frac{365}{\left(\frac{SL-ST}{ADG_{t_0}}\right)+EP}\right) \cdot (RV - (DP + ((SL - ST) \cdot FCR \cdot FP) + DC)) \cdot 10{,}000\ DO}{\frac{365}{\left(\frac{SL-ST}{ADG_{t_0}}\right)+EP}} \qquad (3)$$

where SL is the slaughter weight

ST is the weight at set-up
ADG_{t_i} is the ADG of the intervention flock under review
EP is the empty period
ADG_{t_0} is the average ADG of the historical data
RV is the revenue per broiler
DP is the day-old chick price
DC is the cost of delivery

Table 1. Descriptive statistics technical inputs (mean and standard deviation in parentheses).

Technical input variable	Historical	Observational	Unit
ADG	62.605 (4.010)	64.928 (3.223)	Grams
AMU	152.273 (121.900)	126.531 (93.161)	TI_{1000}
Cycle duration	41.815 (1.484)	41.833 (1.214)	Days
FCR	1.583 (0.059)	1.579 (0.052)	Feed/meat ratio
Mean weight	2.406 (0.146)	2.489 (0.130)	Kilograms
MR	2.543 (1.199)	2.788 (1.048)	Percentage
Number of broilers slaughtered	43,301 (22,301)	42,055 (21,571)	Animals
Number of chicks at set-up	44,478 (22,967)	43,236 (22,146)	Animals

ADG, average daily gain; AMU, antimicrobial use; FCR, feed conversion rate; MR, mortality.

Dividing the overall growth by the ADG provided the duration of the production cycle. The total number of days required for one flock equals the cycle duration plus 14 D, which equals the empty period of the poultry house for cleaning and disinfection. Dividing 365 D by the total number of days required for one flock provides the number of flocks produced per year. The number of flocks per year was estimated with the ADG of the intervention flock (ADG_{t_i}) and the historical ADG (ADG_{t_0}). The difference between the 2 is multiplied by the gross revenue per animal (i.e., slaughter weight multiplied by the producer price), which was corrected for the direct variable costs per broiler (i.e., price of a day-old chick, feed costs, and costs of delivery). The gross margin was multiplied by 10,000 animals at set-up. The outcome was divided by the average number of production cycles per year to make the estimated variables comparable across farms.

Equation 4 shows the calculation of the EV of a change in FCR (EV_{FCR}).

$$EV_{FCR} = \Delta FCR \cdot (SL - SW) \cdot FP \cdot 10{,}000\ DO \tag{4}$$

where ΔFCR is the change in feed conversion rate when comparing average historical data and the intervention flock under review.

The first step in computing the EV_{FCR} was multiplying the change in the FCR by the weight gain (slaughter weight minus starting weight). A lower (higher) FCR indicates that less (more) feed is required. The change in required feed was finally multiplied by both the feed price and 10,000 animals at set-up.

The EV of a change in MR (EV_{MR}) is calculated per flock, using equation 5.

$$EV_{MR} = \Delta MR \cdot 10{,}000\ DO \cdot \left(DP + \left(\frac{(PP \cdot SL) - DP}{2} \right) - DC \right) \tag{5}$$

where ΔMR is the change in mortality when comparing average historical data and the intervention flock under review.

Mortality was assumed to occur in the middle of the production period, and therefore the lost revenue was divided by 2. A side effect of mortality is the cost of delivery that can be subtracted. Fixed costs per broiler may also change because of a change in mortality. However, these potential cost changes are not taken into account in the present study.

Table 2. Economic inputs.

Economic input variable		Unit
Producer price	0.835	€/kg
Feed price	0.315	€/kg
Day-old chick price	0.335	€/animal
Total other variable costs	0.185	€/animal

Source: Blanken et al. (2016).

Gross Margin Analysis

The second step in analyzing the economic impact of tailor-made interventions was gross margin analysis, which measures the difference between the revenue and the variable costs of the farm. The model described by Gocsik et al. (2013) was adapted to calculate the economic impact of intervention on the gross margin. Details about the calculations regarding the gross margins can be found in the Appendix (Table A.6). Subsequently, the average gross margin obtained from historical data was compared with the average gross margin obtained from observational data. The model distinguishes technical inputs and economic inputs.

Table 1 presents the technical inputs. The high standard deviation for the number of broilers slaughtered and number of chicks at set-up is caused by the high variation in the size of the farms included.

The main drivers of farm income are selected as the economic inputs. Revenues and costs determine farm income. Revenues are predominantly driven by the producer price and the slaughter weight. The main cost drivers are feed costs and purchase of day-old chicks (Mollenhorst et al., 2006; Castellini et al., 2012).

Table 2 presents the economic inputs used to calculate both returns and variable costs. The economic input data were derived from the Handbook for Quantitative Information Livestock (Blanken et al., 2016). Although the data do not originate from the same country as the country where the farms in the present study are located, the data may very well reflect the situation as broiler production takes place in similar production systems and under similar market conditions.

Table 3. Results of the Wilcoxon test (z-statistic and P-value in parentheses).

Farm ID	ADG	FCR	MR	AMU	Gross margin
1	−2.364 (0.018)*	−0.798 (0.425)	−1.725 (0.085)†	1.597 (0.110)	−1.026 (0.305)
2	−2.627 (0.009)**	−0.999 (0.318)	−0.946 (0.344)	0.735 (0.462)	1.155 (0.248)
3	1.161 (0.246)	−0.898 (0.369)	−0.844 (0.399)	−0.954 (0.340)	1.265 (0.206)
4	−0.707 (0.480)	0.944 (0.345)	0.826 (0.409)	1.768 (0.077)†	−0.825 (0.409)
5	−1.593 (0.111)	−0.408 (0.683)	−1.952 (0.051)†	−1.676 (0.094)†	−1.857 (0.063)†
6	−2.636 (0.008)**	0.375 (0.708)	−2.676 (0.007)**	3.372 (0.001)**	−0.187 (0.851)
7	−0.050 (0.960)	−1.608 (0.108)	−2.067 (0.039)*	−0.201 (0.841)	1.206 (0.228)
8	0.317 (0.751)	2.258 (0.024)*	−0.705 (0.481)	−1.586 (0.113)	−1.657 (0.098)†
9	−3.465 (0.001)**	1.771 (0.077)†	−0.627 (0.531)	−0.037 (0.971)	−1.769 (0.077)†
10	−2.406 (0.016)*	1.405 (0.160)	−0.301 (0.764)	0.735 (0.462)	−3.274 (0.001)**
11	−0.053 (0.958)	1.695 (0.090)†	−2.172 (0.030)*	3.334 (0.001)**	1.323 (0.186)
12	0.525 (0.600)	0.315 (0.753)	1.155 (0.248)	1.470 (0.142)	−0.630 (0.529)
13	−2.172 (0.030)*	−0.832 (0.405)	−1.768 (0.077)†	0.794 (0.427)	−1.234 (0.217)
14	−0.945 (0.345)	0.841 (0.401)	1.261 (0.207)	0.105 (0.916)	−1.785 (0.074)†
15	−0.714 (0.475)	−1.367 (0.172)	−2.286 (0.022)*	−1.857 (0.063)†	1.857 (0.063)†
16	−0.265 (0.791)	−1.403 (0.161)	−1.579 (0.114)	−0.040 (0.968)	1.754 (0.079)†
17	1.775 (0.076)†	2.470 (0.014)*	−0.425 (0.671)	0.772 (0.440)	−2.392 (0.017)*
18	−1.960 (0.050)†	1.958 (0.050)†	1.429 (0.153)	1.852 (0.064)†	−1.217 (0.224)
19	−2.556 (0.011)*	2.018 (0.044)*	−1.006 (0.314)	−1.278 (0.201)	−1.095 (0.273)
20	−3.130 (0.002)**	−3.258 (0.001)**	−2.432 (0.015)*	0.463 (0.643)	3.240 (0.001)**

† $P \leq 0.10$, * $P \leq 0.05$, and ** $P \leq 0.01$.
ADG, average daily gain; AMU, antimicrobial use; FCR, feed conversion rate; MR, mortality.

Sensitivity Analysis

Prices in broiler production are characterized by high volatility. Therefore, a sensitivity analysis was conducted to assess the effect of ±5% and ±10% changes in producer price, feed price, and day-old chick price on the EV of the changes in technical performance and gross margins. Since the economic impact is standardized to 10,000 animals at set-up, the effect of changes in day-old chick price on the gross margin cannot assessed.

RESULTS

On-Farm Interventions

During the intervention period, 119 interventions were carried out. An overview of the interventions is presented in the Appendix (see Table A.7). About 51.26% of the interventions undertaken targeted the animals (i.e., disease management), 19.33% of the interventions targeted the farmer, and 29.41% targeted the farm (i.e., farm management). Interventions were mainly addressing coccidiosis, feed, and training of the farmer. Costs of applying the interventions were not included in the present study. However, the change in gross margin when comparing the historical data and the observational data gives an indication of the maximum price an economically rational farmer is willing to pay for the intervention(s). An economically farmer is a farmer who takes decisions consistent with his/her own subjectively defined goals (Hardaker et al., 2015).

Comparing Historical and Observational Data

Table 3 shows the z statistic and P-value resulting from the Wilcoxon rank-sum test. The results indicate a significant difference between the historical and the observational data on 10 different farms with respect to ADG. In addition, significant differences are found on 7 farms with respect to FCR, and a significant difference for MR was found on 8 farms. For AMU, a significant difference was found on 6 farms, whereas a significant difference in gross margin was found on 9 farms.

Table 4. Probability that the random draw of the variable of the historical data is larger than the random draw from the variable of the observational data.

Farm ID	ADG	FCR	MR	AMU	Gross margin
1	0.122*	0.333	0.224†	0.755	0.286
2	0.109**	0.352	0.359	0.609	0.672
3	0.683	0.358	0.367	0.354	0.700
4	0.389	0.648	0.630	0.778†	0.370
5	0.273	0.442	0.221†	0.260†	0.234†
6	0.111**	0.556	0.104**	1.000**	0.472
7	0.492	0.258	0.189*	0.470	0.682
8	0.543	0.805*	0.405	0.286	0.276†
9	0.010**	0.750†	0.411	0.495	0.250†
10	0.179*	0.688	0.460	0.598	0.063**
11	0.492	0.754†	0.175*	1.000**	0.698
12	0.578	0.547	0.672	0.719	0.406
13	0.175*	0.333	0.222†	0.619	0.278
14	0.359	0.625	0.688	0.516	0.234†
15	0.381	0.274	0.119*	0.190†	0.810†
16	0.462	0.295	0.269	0.495	0.756†
17	0.740†	0.833*	0.443	0.604	0.177*
18	0.206†	0.794†	0.714	0.778†	0.317
19	0.033*	0.867*	0.317	0.267	0.300
20	0.018**	0.000**	0.125*	0.571	1.000**

† $P \leq 0.10$, * $P \leq 0.05$, and ** $P \leq 0.01$.
ADG, average daily gain; AMU, antimicrobial use; FCR, feed conversion rate; MR, mortality.

Table 4 shows the probability that a random draw from the historical data of the selected dependent variable is larger than the observational data. For example, the probability scores of 1.00 indicates that a random draw from the historical data with respect AMU is always larger than a random draw from the observational data.

Table 5. Results economic value (EV) of changes in technical performance (standardized to 10,000 animals at set-up) shown as average per farm with standard deviation in parentheses.

Farm ID	EV_{ADG} constant cycle duration (€)	EV_{ADG} constant slaughter weight (€)	EV_{FCR} (€)	EV_{MR} (€)
1	676 (254)	283 (124)	−379 (244)	−90 (128)
2	623 (399)	257 (164)	−222 (337)	−36 (90)
3	−325 (363)	−115 (123)	−71 (144)	−53 (105)
4	273 (443)	129 (200)	129 (282)	80 (65)
5	395 (504)	170 (206)	−27 (294)	−57 (45)
6	468 (423)	193 (189)	82 (724)	−100 (93)
7	32 (501)	29 (187)	−734 (634)	−77 (73)
8	−28 (428)	−7 (165)	315 (175)	−31 (85)
9	919 (280)	382 (136)	341 (313)	−58 (162)
10	268 (201)	108 (83)	117 (213)	−9 (85)
11	19 (233)	11 (97)	142 (209)	−92 (40)
12	−85 (361)	−24 (125)	79 (335)	145 (107)
13	428 (335)	179 (142)	−49 (330)	−49 (62)
14	192 (389)	75 (140)	114 (258)	82 (95)
15	128 (268)	49 (97)	−123 (129)	−133 (87)
16	59 (452)	39 (194)	−228 (411)	−146 (230)
17	−173 (285)	−65 (105)	331 (290)	28 (66)
18	405 (442)	174 (182)	481 (257)	101 (67)
19	1,554 (926)	703 (472)	490 (214)	−86 (154)
20	891 (216)	394 (110)	−699 (249)	−144 (126)
Average (Std. deviation)	336 (442)	148 (190)	5 (338)	−36 (83)

Economic Value of Changes in Technical Performance

Table 5 shows the results of the EV of changes in technical performance. For each farm, the EV is calculated by comparing the average technical performance based on the average historical data with the technical performance for all observational flocks separately. Results presented in Table 5 are the average EV per farm for each technical performance indicator. In addition, an overall average for all farms is indicated. The standard deviations are shown in parentheses. The results show that the EV of the change in ADG (for both calculations) and FCR were generally positive, whereas the change in MR was generally negative. The EV when assuming a constant cycle duration is structurally higher compared to the EV when assuming a constant slaughter weight. The standard deviations are high relative to the mean value, which indicates high variability among the EVs. The equations used to calculate the EV of the change in technical performance are interlinked (i.e., the equation of one technical performance parameter also depends on one or more other technical performance parameters). Hence, the EV of the changes in technical performance have to be assessed individually and adding the EV of the different performance indicators would provide an overestimation of the effect.

Gross Margin Analysis

Within the gross margin analysis, the difference between the average gross margin based on the historical data and the average gross margin based on the observational data was calculated per farm. Table 6 shows the average of these differences in gross margin per farm, both in absolute and relative terms. In addition, the change in AMU (both in absolute and relative terms) is shown for each farm. Although the results show different combinations regarding the change in gross margin and AMU, the results generally indicate that a decrease in AMU does not have negative consequences for economic performance.

Table 6. Change in gross margin and antimicrobial use (AMU) when comparing the historical data and the observational data.

Farm ID	Δ Gross margin (€)	Δ Gross margin (%)	Δ AMU (TI_{1000})	Δ AMU (%)
1	359	32	−41	−20
2	−394	−26	−60	−36
3	−295	−18	39	19
4	294	23	−58	−41
5	545	24	45	99
6	−42	−2	−307	−362
7	−413	−25	−1	−1
8	830	42	53	57
9	648	64	31	32
10	639	41	−2	−1
11	−299	−24	−230	−57
12	243	20	−57	−60
13	408	23	−34	−26
14	783	56	−5	−4
15	−399	−28	13	17
16	−569	−25	7	5
17	547	78	−39	−18
18	580	43	−36	−15
19	490	46	67	34
20	−1,149	−67	−61	−31
Average (Std. deviation)	140 (546)	14	–34 (91)	−20

Table 7 shows the results of the change in gross margin and AMU for the semi-control farms (both in absolute and relative terms). When comparing the results of the intervention farms and the semi-control farms,

Table 7. Results of the change in gross margin and antimicrobial use (AMU) when comparing the historical data and the observational data of the (non-intervention) semi-control farms.

Farm ID	Δ Gross margin (€)	Δ Gross margin (%)	Δ AMU (TI_{1000})	Δ AMU (%)
1	−452	−18	−5	−4
2	223	18	12	7
3	−333	−11	114	359
4	−1,195	−47	−39	−51
5	−768	−34	21	9
6	−651	−23	3	3
7	−420	−16	−12	−8
8	−576	−28	51	173
9	790	48	12	11
10	−1,546	−86	135	208
11	−1,264	−44	3	2
12	−158	-9	−36	−20
13	804	79	−66	−21
Average (Std. deviation)	−427 (721)	−13 (42)	15 (57)	51 (120)

some differences can be observed. For the semi-control farms, the gross margin generally decreased while AMU increased. For only farm (i.e., farm 13), a decrease in AMU coincided with an increase in economic performance.

Sensitivity Analyses

Table 8 shows the results of the sensitivity analyses for both the EV of the change in technical performance and the gross margin. The numbers shown in the table are an average for all farms in the sample. The average EV of a change in a technical performance parameter and the average gross margin are only shown when either the EV or the gross margin changes due to a price change. A change in the producer price affects the EV_{MR}, both calculations of the EV_{ADG}, and the gross margin. The EV_{MR} has a small negative relationship with the producer price, while both estimations of the EV_{ADG} have a strong positive relationship with the producer price and the gross margin.

A change in the feed price influences the EV_{FCR}, both calculations of the EV_{ADG}, and the gross margin. The EV_{FCR} has a positive relation with the feed price. There is a negative relationship between both estimations of the EV_{ADG} and the feed price. If the feed price increases, the gross profit margin per broiler decreases, and consequently the EV_{ADG} decreases. Hence, the gross margin also has a negative relationship with the feed price.

The price of a day-old chick affects both the EV_{MR} and the $EV_{ADG\ constant\ weight}$. The effect of a change in day-old chick price on the EV_{MR} is limited. There is a negative relationship between the $EV_{ADG\ constant\ weight}$ and the price of a day-old chick, since an increase in day-old chick price decreases the gross profit margin. Since the gross margin is standardized for a default farm with 10,000 animals at set-up, no effect of changes in day-old chick price are observed.

The results of the sensitivity analyses (see Table 8) indicate that the difference in the gross margin before and after intervention, both expressed per 10,000 animals at set-up, is always positive (even when the producer price drops with 10% or when the feed price increases by 10%). Hence, an economically rational farmer who takes decisions consistent with his/her own subjectively defined goals (Hardaker et al., 2015) will apply the intervention as long as the economic value of the intervention is greater than the costs of applying the intervention.

DISCUSSION

The aim of this study was to analyze the effects of tailor-made interventions, aimed at reducing (the need for) AMU, on technical and economic farm performance on broiler farms. Only few studies in the domain of commercial broiler production focused on building blocks for interventions to reduce AMU. Caucci et al. (2019) identified several factors that inform the design of interventions to further reduce AMU in broiler production and therefore counteract AMR in this sector. However, to the best of our knowledge no studies assessed the effect of on-farm interventions aimed at reducing AMU on the technical and economic farm performance, and AMU in commercial broiler farms. The lack of published research on interventions to reduce AMU in broiler flocks highlights the importance and novelty of the present study. The results of the present study can therefore only be compared to similar studies carried out in commercial pig production.

Table 8. Results sensitivity analysis on the economic value of changes in technical performance and the gross margin of the intervention farms (indices are shown in parentheses).

Price	Performance parameter	10% price decrease	5% price decrease	Baseline	5% price increase	10% price increase
Producer price	EV $ADG_{constant\ cycle\ duration}$	253 (75)	295 (88)	336 (100)	377 (112)	419 (125)
	EV $ADG_{constant\ weight}$	86 (58)	117 (79)	148 (100)	179 (121)	210 (142)
	EV MR	−33 (91)	−35 (96)	−36 (100)	−38 (104)	−39 (109)
	Δ Gross margin	80 (57)	110 (78)	140 (100)	171 (122)	201 (143)
Feed price	EV FCR	4 (90)	4 (95)	5 (100)	5 (105)	5 (110)
	EV $ADG_{constant\ cycle\ duration}$	385 (115)	361 (107)	336 (100)	312 (93)	287 (85)
	EV $ADG_{constant\ weight}$	185 (125)	166 (112)	148 (100)	130 (88)	112 (76)
	Δ Gross margin	187 (133)	164 (117)	140 (100)	117 (83)	94 (67)
Day-old chick price	EV $ADG_{constant\ weight}$	159 (107)	154 (103)	148 (100)	144 (97)	139 (93)
	EV MR	−36 (99)	−36 (99)	−36 (100)	−36 (101)	−37 (101)

Results of this study indicate that ADG generally increased after intervention. Rojo-Gimeno et al. (2016) found similar results in a study regarding the effects of interventions in farrow-to-finish pig farms in Flanders (i.e., northern region in Belgium). FCR generally decreased after intervention on the broiler farms. Postma et al. (2017) found similar results in Flemish pig production. Generally, mortality increased after intervention in the present study, which contrasts the results of Rojo-Gimeno et al. (2016) and Postma et al. (2017) with respect to farrow-to-finish pig farms in Belgium. A possible explanation for the increase in mortality is that the persuasive interventions applied in the present study partly aim to develop rules to omit preventive treatments and limit to curative treatments. Interventions might result in increased mortality when the application was incorrect or when the effect was insufficient. AMU generally decreased on the farms in the sample. This result is in line with the results of Rojo-Gimeno et al. (2016) and Postma et al. (2017) with respect to farrow-to-finish pig farms in Belgium. Postma et al. (2017) even found a reduction in AMU of more than 50%.

Statistical tests in the present study were limited to the degree of change in AMU, technical farm performance, and economic farm performance for each individual farm. Assessing causal dose–response relations was therefore not possible. However, the most frequently employed interventions in the present study were coccidiosis control, feed, and training of the farmer (see Table A.7). Coccidiosis is the most important protozoan disease affecting the poultry industry (including broiler production) worldwide, and the control of coccidiosis is currently mainly based on managerial skills and the use of anticoccidial feed additives (Tewari and Maharana, 2011). Given the importance of the training of the farmer, knowing farmer AMU behaviours is essential. Speksnijder and Wagenaar (2018) have provided a review of common AMU behaviours and potential actions to change the behaviour of farmers with respect to AMU. However, interventions for changing AMU behaviours are more likely to occur on farms with antimicrobial overuse. Possibilities for improvement in technical and economic farm performance on these farms are therefore less obvious.

Sensitivity analysis has shown that the results with respect to economic farm performance are robust. Results from semi-control farms indicate that gross margins generally decreased, whereas AMU generally increased over the same period. This outcome strengthens the finding that interventions can have a positive impact on AMU, technical performance, and economic performance. However, the results of this study fail to provide a proof for the causality of the relations between interventions and impacts on both farm performance and AMU. In addition, application costs of intervention and the changing health care costs resulting from the observed change in AMU were not taking into account in this study since data regarding these costs were missing. Future research should therefore focus on testing the causality of relations between intervention, technical farm performance, economic farm performance, and AMU. In addition, costs of applying both intervention and AMU have to be incorporated in future studies.

Although the present study focused on broiler farms from one specific country, the findings are relevant for countries that face similar concerns with respect to reducing AMU (e.g., other European countries) and develop their production in a similar direction. However, participation in the survey used in the present study was voluntary, and therefore it is likely that participating farmers were more intrinsically motivated to reduce AMU. In that respect, effects of intervention might be different when interventions are mandatory.

To conclude, results of the present study have shown that intervention can result in reduced AMU. In addition, the results show that a decrease in AMU does not have negative consequences for both technical and economic farm performance.

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APPENDIX

Table A.1. Overview of missing data and (potential) outliers.

Farm ID	Flock	Type of data	Parameter	Explanation
1	1, 2, 4–7	Historical	FCR	All values were checked by the veterinarian; the values of the first 2 flocks were correct, the values of the last 4 flocks were incorrect and therefore removed
3	10	Observational	ADG, FCR, and MR	Missing data; data could not be obtained
6	8–12	Observational	ADG	All values were checked by the veterinarian; and replaced by the correct data
7	2, 4	Historical	FCR	Not enough evidence to assume that the observations were incorrect
7	10, 11	Observational	ADG	All values were checked by the veterinarian; and replaced by the correct data
8	1	Historical	ADG	The value was checked by the veterinarian and corrected afterwards
9	13–16	Observational	FCR	All values were checked by the veterinarian, and replaced by the correct data
11	3–5	Historical	MR	Not enough evidence to assume that the observations were incorrect
12	6	Historical	FCR	The value was checked by the veterinarian, and appeared to be correct
12	5	Observational	FCR	The value was checked by the veterinarian, and appeared to be correct
13	1, 3, 5, and 6	Historical	FCR	All values were checked by the veterinarian; the value of the first flock was corrected, the values of the other flocks were incorrect and therefore removed
13	3	Historical	MR	Not enough evidence to assume that the observation was incorrect
13	7	Historical	MR	Missing observation; data could not be obtained
14	1	Historical	ADG	The value was checked by the veterinarian and corrected afterwards
16	5	Historical	MR	Not enough evidence to assume that the observation was incorrect
16	5	Historical	MR	The veterinarian checked the value; in this flock, there were problems in the climate control within the stable. Consequently, all technical performance indicators of this flock were considered as outlier and removed.
19	3	Observational	ADG	The value was checked by the veterinarian, and appeared to be correct

Table A.2. Results Wilcoxon rank-sum test (z-statistic and P-value) regarding the average daily gain after excluding intervention flocks one by one.

	All	−1	−2	−3	−4	−5	−6	−7	−8	−9	−10	−11	−12	−13	−14	−15
1	−2.364 (0.018)*	−2.429 (0.015)*	−2.192 (0.028)*	−2.268 (0.023)*	−1.937 (0.053)†	−1.464 (0.143)	−1.091 (0.275)	NA	NA	NA	NA	NA	NA	NA	NA	NA
2	−2.627 (0.009)**	−2.432 (0.015)*	−2.197 (0.028)*	−2.052 (0.040)*	−1.701 (0.089)†	−1.228 (0.220)	−1.833 (0.067)†	−1.167 (0.243)	NA	NA	NA	NA	NA	NA	NA	NA
3	1.161 (0.246)	1.190 (0.234)	1.226 (0.220)	1.001 (0.317)	0.733 (0.464)	0.732 (0.464)	0.915 (0.360)	0.943 (0.346)	0.984 (0.325)	0.450 (0.653)	0.450 (0.653)	0.000 (1.000)	0.297 (0.766)	NA	NA	NA
4	−0.707 (0.480)	−0.387 (0.699)	−0.714 (0.475)	−0.801 (0.423)	−0.730 (0.465)	−0.853 (0.394)	−0.258 (0.796)	−0.667 (0.505)	−1.000 (0.317)	NA	NA	NA	NA	NA	NA	NA
5	−1.593 (0.111)	−1.473 (0.141)	−1.226 (0.220)	−1.051 (0.293)	−0.840 (0.401)	−0.579 (0.562)	−1.075 (0.283)	−0.774 (0.439)	−0.353 (0.724)	0.612 (0.541)	−0.697 (0.486)	NA	NA	NA	NA	NA
6	−2.636 (0.008)**	−2.528 (0.012)*	−2.841 (0.005)**	−2.735 (0.006)**	−2.611 (0.009)**	−2.463 (0.014)*	−2.934 (0.003)**	−2.803 (0.005)**	−2.640 (0.008)**	−2.427 (0.015)*	−2.131 (0.033)*	−1.655 (0.098)†	NA	NA	NA	NA
7	−0.050 (0.960)	0.272 (0.786)	0.296 (0.767)	0.325 (0.746)	0.072 (0.943)	0.081 (0.936)	0.646 (0.518)	1.407 (0.159)	0.923 (0.356)	0.342 (0.733)	0.000 (1.000)	NA	NA	NA	NA	NA
8	0.317 (0.751)	0.298 (0.765)	0.119 (0.905)	0.085 (0.933)	0.317 (0.751)	0.293 (0.770)	−0.053 (0.958)	−0.347 (0.729)	−0.447 (0.655)	−0.857 (0.391)	−1.056 (0.291)	−1.134 (0.257)	−0.570 (0.569)	0.293 (0.770)	0.218 (0.827)	NA
9	−3.465 (0.001)**	−3.425 (0.001)**	−3.382 (0.001)**	−3.333 (0.001)**	−3.278 (0.001)**	−3.216 (0.001)**	−3.145 (0.002)**	−3.064 (0.002)**	−3.098 (0.002)**	−3.000 (0.003)**	−2.882 (0.004)**	−2.739 (0.006)**	−2.558 (0.011)*	−2.324 (0.020)*	−2.000 (0.046)*	−1.500 (0.134)
10	−2.406 (0.016)*	−2.362 (0.018)*	−2.239 (0.025)*	−2.101 (0.036)*	−1.945 (0.052)†	−2.039 (0.042)*	−1.854 (0.064)†	−2.170 (0.030)*	−2.083 (0.037)*	−1.853 (0.064)†	−1.714 (0.087)†	−1.380 (0.168)	−1.134 (0.257)	−0.570 (0.569)	−1.171 (0.242)	−1.528 (0.127)
11	−0.053 (0.958)	−0.231 (0.817)	0.064 (0.949)	−0.143 (0.886)	−0.568 (0.570)	−0.756 (0.450)	−0.114 (0.909)	0.293 (0.770)	0.218 (0.827)	NA	NA	NA	NA	NA	NA	NA
12	0.525 (0.600)	0.231 (0.817)	0.000 (1.000)	−0.146 (0.884)	0.170 (0.865)	0.408 (0.683)	0.783 (0.433)	0.775 (0.439)	NA	NA	NA	NA	NA	NA	NA	NA
13	−2.172 (0.030)*	−2.085 (0.037)*	−1.855 (0.064)†	−2.003 (0.045)*	−2.196 (0.028)*	−1.894 (0.058)†	−1.486 (0.137)	−2.058 (0.040)*	−1.537 (0.124)	NA	NA	NA	NA	NA	NA	NA
14	−0.945 (0.345)	−0.810 (0.418)	−1.033 (0.302)	−1.317 (0.188)	−1.189 (0.235)	−1.021 (0.307)	−2.089 (0.037)*	−1.549 (0.121)	NA	NA	NA	NA	NA	NA	NA	NA
15	−0.714 (0.475)	−1.056 (0.291)	−0.756 (0.450)	−0.114 (0.909)	0.000 (1.000)	0.218 (0.827)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16	−0.265 (0.791)	−0.094 (0.925)	0.101 (0.919)	−0.109 (0.913)	−0.357 (0.721)	−0.653 (0.514)	−1.014 (0.311)	−0.815 (0.415)	−0.561 (0.575)	−0.220 (0.826)	−0.809 (0.419)	−1.776 (0.076)†	−1.103 (0.270)	NA	NA	NA
17	1.775 (0.076)†	1.900 (0.057)†	2.134 (0.033)*	2.407 (0.016)*	2.207 (0.027)*	2.085 (0.037)*	1.939 (0.053)†	1.759 (0.079)†	1.531 (0.126)	1.228 (0.220)	0.786 (0.432)	0.000 (1.000)	NA	NA	NA	NA
18	−1.960 (0.050)†	−2.548 (0.011)*	−2.622 (0.009)†	−2.575 (0.010)*	−2.359 (0.018)*	−2.273 (0.023)*	−1.943 (0.052)†	−1.470 (0.142)	−1.098 (0.272)	NA	NA	NA	NA	NA	NA	NA
19	−2.556 (0.011)*	−2.402 (0.016)*	−2.449 (0.014)*	−2.236 (0.025)*	−1.936 (0.053)†	−1.464 (0.143)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20	−3.130 (0.002)**	−3.009 (0.003)**	−2.865 (0.004)**	−2.689 (0.007)**	−2.468 (0.014)*	−2.178 (0.029)*	−1.771 (0.077)†	−1.546 (0.122)	NA	NA	NA	NA	NA	NA	NA	NA

$^{\dagger}P \leq 0.10$, $^{*}P \leq 0.05$, and $^{**}P \leq 0.01$.

Table A.3. Results Wilcoxon rank-sum test (z-statistic and P-value) regarding the feed conversion rate after excluding intervention flocks one by one.

	All	−1	−2	−3	−4	−5	−6	−7	−8	−9	−10	−11	−12	−13	−14	−15
1	−0.798	−0.775	−0.745	−0.707	−0.655	−0.577	−0.447	NA	NA	NA	NA	NA	NA	NA	NA	NA
	(0.425)	(0.439)	(0.456)	(0.480)	(0.513)	(0.564)	(0.655)									
2	−0.999	−0.985	−0.970	−0.954	−0.426	−0.103	0.394	0.000	NA	NA	NA	NA	NA	NA	NA	NA
	(0.318)	(0.324)	(0.332)	(0.340)	(0.670)	(0.918)	(0.694)	(1.000)								
3	−0.898	−0.795	−0.736	−0.734	−0.733	−0.732	−0.549	−0.524	−0.246	0.150	0.150	0.782	1.485	NA	NA	NA
	(0.369)	(0.427)	(0.462)	(0.463)	(0.464)	(0.464)	(0.583)	(0.600)	(0.806)	(0.881)	(0.881)	(0.434)	(0.138)			
	0.944	1.034	0.715	0.642	1.098	0.855	0.519	0.335	1.514	NA	NA	NA	NA	NA	NA	NA
	(0.345)	(0.301)	(0.474)	(0.521)	(0.272)	(0.392)	(0.604)	(0.737)	(0.130)							
5	−0.408	−0.293	−0.053	0.231	0.575	1.000	0.893	0.756	0.570	−0.293	1.091	NA	NA	NA	NA	NA
	(0.683)	(0.770)	(0.958)	(0.817)	(0.565)	(0.317)	(0.372)	(0.450)	(0.569)	(0.770)	(0.275)					
6	0.375	0.201	0.434	0.826	0.775	0.429	0.962	0.548	0.000	−0.258	−1.333	−1.500	NA	NA	NA	NA
	(0.708)	(0.841)	(0.664)	(0.409)	(0.438)	(0.668)	(0.336)	(0.584)	(1.000)	(0.796)	(0.182)	(0.134)				
7	−1.608	−1.519	−1.414	−1.291	−1.000	−0.641	−0.913	−0.426	−0.516	−1.000	−1.000	NA	NA	NA	NA	NA
	(0.108)	(0.129)	(0.157)	(0.197)	(0.317)	(0.522)	(0.361)	(0.670)	(0.606)	(0.317)	(0.317)					
8	2.258	2.128	2.062	1.903	1.723	1.612	1.536	1.389	1.214	0.857	1.056	0.567	0.570	0.293	−0.218	NA
	(0.024)*	(0.033)*	(0.039)*	(0.057)†	(0.085)†	(0.107)	(0.125)	(0.165)	(0.225)	(0.391)	(0.291)	(0.571)	(0.569)	(0.770)	(0.827)	
9	1.771	1.636	1.486	1.317	1.125	1.308	1.086	0.826	0.518	0.143	−0.321	−0.367	−0.215	0.000	0.671	−0.505
	(0.077)†	(0.102)	(0.137)	(0.188)	(0.261)	(0.191)	(0.277)	(0.409)	(0.605)	(0.886)	(0.748)	(0.714)	(0.830)	(1.000)	(0.502)	(0.614)
10	1.405	1.377	1.346	1.309	1.354	1.315	1.759	1.749	1.507	1.473	2.149	2.200	2.084	2.172	2.058	1.537
	(0.160)	(0.169)	(0.179)	(0.191)	(0.176)	(0.189)	(0.079)†	(0.080)†	(0.132)	(0.141)	(0.032)*	(0.028)*	(0.037)*	(0.030)*	(0.040)*	(0.124)
11	1.695	1.448	1.535	1.216	1.218	2.079	1.709	1.171	1.528	NA	NA	NA	NA	NA	NA	NA
	(0.090)†	(0.148)	(0.125)	(0.224)	(0.223)	(0.038)*	(0.087)†	(0.242)	(0.127)							
12	0.315	0.695	1.034	1.319	1.361	0.818	0.262	1.167	NA	NA	NA	NA	NA	NA	NA	NA
	(0.753)	(0.487)	(0.301)	(0.187)	(0.174)	(0.413)	(0.793)	(0.243)								
13	−0.832	−0.816	−0.798	−0.775	−0.745	−0.707	−0.655	−0.577	−0.447	NA	NA	NA	NA	NA	NA	NA
	(0.405)	(0.414)	(0.425)	(0.439)	(0.456)	(0.480)	(0.513)	(0.564)	(0.655)							
14	0.841	0.579	1.034	1.319	1.701	1.228	2.095	1.556	NA	NA	NA	NA	NA	NA	NA	NA
	(0.401)	(0.563)	(0.301)	(0.187)	(0.089)†	(0.220)	(0.036)*	(0.120)								
15	−1.367	−1.063	−1.144	−1.038	−0.596	−1.098	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	(0.172)	(0.288)	(0.253)	(0.299)	(0.552)	(0.272)										
16	−1.403	−1.499	−1.407	−1.302	−1.061	−0.904	−0.857	−0.480	0.000	0.426	1.291	2.000	1.500	NA	NA	NA
	(0.161)	(0.134)	(0.159)	(0.193)	(0.289)	(0.366)	(0.391)	(0.631)	(1.000)	(0.670)	(0.197)	(0.046)*	(0.134)			
17	2.470	2.561	3.111	3.081	2.943	2.893	2.840	2.781	2.717	2.449	2.089	1.549	NA	NA	NA	NA
	(0.014)*	(0.010)*	(0.002)**	(0.002)**	(0.003)**	(0.004)**	(0.005)**	(0.005)**	(0.007)**	(0.014)*	(0.037)*	(0.121)				
18	1.958	1.852	1.853	2.000	1.868	1.890	1.709	1.464	1.091	NA	NA	NA	NA	NA	NA	NA
	(0.050)†	(0.064)†	(0.064)†	(0.046)*	(0.062)†	(0.059)†	(0.087)†	(0.143)	(0.275)							
19	2.018	1.997	1.729	1.358	0.789	1.508	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	(0.044)*	(0.046)*	(0.084)	(0.175)	(0.430)	(0.132)										
20	−3.258	−3.148	−3.021	−2.867	−2.676	−2.430	−2.093	−1.575	NA	NA	NA	NA	NA	NA	NA	NA
	(0.001)**	(0.002)**	(0.003)**	(0.004)**	(0.007)**	(0.015)*	(0.036)*	(0.115)								

† $P \leq 0.10$, * $P \leq 0.05$, and ** $P \leq 0.01$.

Table A.4. Results Wilcoxon rank-sum test (z-statistic and P-value) regarding mortality after excluding intervention flocks one by one.

	All	−1	−2	−3	−4	−5	−6	−7	−8	−9	−10	−11	−12	−13	−14	−15
1	−1.725	−1.571	−1.380	−1.512	−1.937	−1.464	−1.091	NA	NA	NA	NA	NA	NA	NA	NA	NA
	(0.085)†	(0.116)	(0.168)	(0.131)	(0.053)*	(0.143)	(0.275)									
2	−0.946	−1.390	−1.422	−1.026	−1.361	−1.841	−1.310	−0.389	NA	NA	NA	NA	NA	NA	NA	NA
	(0.344)	(0.165)	(0.155)	(0.305)	(0.174)	(0.066)†	(0.190)	(0.697)								
3	−0.844	−0.737	−0.858	−0.601	−0.293	0.081	−0.366	−0.524	−0.738	−1.050	−1.050	−0.391	0.891	NA	NA	NA
	(0.399)	(0.461)	(0.391)	(0.548)	(0.769)	(0.935)	(0.714)	(0.600)	(0.461)	(0.294)	(0.294)	(0.696)	(0.373)			
4	0.826	0.775	0.714	0.641	0.913	0.853	0.775	0.667	0.500	NA	NA	NA	NA	NA	NA	NA
	(0.409)	(0.439)	(0.475)	(0.522)	(0.361)	(0.394)	(0.439)	(0.505)	(0.617)							
5	−1.952	−1.958	−2.072	−2.092	−2.120	−2.158	−2.212	−2.294	−2.430	−2.093	−1.575	NA	NA	NA	NA	NA
	(0.051)†	(0.050)†	(0.038)*	(0.036)*	(0.034)*	(0.031)*	(0.027)*	(0.022)*	(0.015)*	(0.036)*	(0.115)					
6	−2.676	−2.571	−2.611	−2.536	−2.520	−2.503	−2.402	−2.373	−2.345	−2.066	−1.667	−1.000	NA	NA	NA	NA
	(0.007)**	(0.010)*	(0.009)**	(0.011)*	(0.012)*	(0.012)*	(0.016)*	(0.018)*	(0.019)*	(0.039)*	(0.096)†	(0.317)				
7	−2.067	−2.232	−2.538	−2.394	−2.220	−2.009	−2.745	−2.566	−2.334	−2.012	−1.514	NA	NA	NA	NA	NA
	(0.039)*	(0.026)*	(0.011)*	(0.017)*	(0.026)*	(0.045)*	(0.006)**	(0.010)*	(0.020)*	(0.044)*	(0.130)					
8	−0.705	−0.485	−0.238	0.042	−0.181	−0.146	−0.424	−0.869	−0.512	−0.644	−0.651	−1.421	−1.481	−2.049	−1.528	NA
	(0.481)	(0.628)	(0.812)	(0.966)	(0.856)	(0.884)	(0.672)	(0.385)	(0.609)	(0.520)	(0.515)	(0.155)	(0.139)	(0.040)*	(0.127)	
9	−0.627	−0.428	−0.206	−0.263	−0.281	−0.302	−0.326	−0.354	−0.258	−0.286	−0.481	−0.732	−0.855	−0.259	0.671	0.505
	(0.531)	(0.668)	(0.837)	(0.792)	(0.779)	(0.763)	(0.745)	(0.723)	(0.796)	(0.775)	(0.630)	(0.464)	(0.392)	(0.795)	(0.502)	(0.614)
10	−0.301	−0.212	−0.187	−0.277	−0.423	−0.770	−0.684	−0.900	−1.042	−0.959	−0.857	−0.731	−0.567	−0.342	0.000	0.655
	(0.764)	(0.832)	(0.852)	(0.781)	(0.673)	(0.441)	(0.494)	(0.368)	(0.297)	(0.337)	(0.391)	(0.465)	(0.571)	(0.732)	(1.000)	(0.513)
11	−2.172	−2.083	−1.981	−1.857	−1.705	−1.512	−1.254	−1.171	−1.091	NA	NA	NA	NA	NA	NA	NA
	(0.030)*	(0.037)*	(0.048)*	(0.063)†	(0.088)†	(0.131)	(0.210)	(0.242)	(0.275)							
12	1.155	1.273	1.420	1.610	1.189	0.816	1.044	0.775	NA	NA	NA	NA	NA	NA	NA	NA
	(0.248)	(0.203)	(0.156)	(0.107)	(0.235)	(0.414)	(0.296)	(0.439)								
13	−1.768	−1.549	−1.571	−1.441	−1.278	−1.279	−1.033	−1.000	−0.500	NA	NA	NA	NA	NA	NA	NA
	(0.077)†	(0.121)	(0.116)	(0.150)	(0.201)	(0.201)	(0.302)	(0.317)	(0.617)							
14	1.261	0.927	1.422	1.026	0.851	0.612	0.261	1.162	NA	NA	NA	NA	NA	NA	NA	NA
	(0.207)	(0.354)	(0.155)	(0.305)	(0.395)	(0.540)	(0.794)	(0.245)								
15	−2.286	−2.030	−1.701	−1.254	−2.049	−1.528	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	(0.022)*	(0.042)*	(0.089)†	(0.210)	(0.040)	(0.127)										
1	−1.579	−1.499	−1.307	−1.193	−1.061	−1.549	−1.286	−0.961	−0.548	−0.213	−0.775	−1.667	−1.000	NA	NA	NA
	(0.114)	(0.134)	(0.191)	(0.233)	(0.289)	(0.121)	(0.199)	(0.337)	(0.584)	(0.831)	(0.439)	(0.096)†	(0.317)			
1	−0.425	−0.290	−0.045	0.145	0.368	0.231	0.516	0.146	0.170	0.612	−0.261	−1.162	NA	NA	NA	NA
	(0.671)	(0.772)	(0.965)	(0.885)	(0.713)	(0.817)	(0.606)	(0.884)	(0.865)	(0.540)	(0.794)	(0.245)				
18	1.429	1.389	1.086	1.000	1.218	0.945	0.342	0.293	−0.218	NA	NA	NA	NA	NA	NA	NA
	(0.153)	(0.165)	(0.277)	(0.317)	(0.223)	(0.345)	(0.732)	(0.770)	(0.827)							
19	−1.006	−0.629	−0.735	−1.640	−1.936	−1.464	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	(0.314)	(0.530)	(0.462)	(0.101)	(0.053)†	(0.143)										
20	−2.432	−2.366	−2.289	−2.034	−1.701	−1.254	−1.464	−1.091	NA	NA	NA	NA	NA	NA	NA	NA
	(0.015)*	(0.018)*	(0.022)*	(0.042)*	(0.089)†	(0.210)	(0.143)	(0.275)								

†$P \leq 0.10$, *$P \leq 0.05$, and **$P \leq 0.01$.

Table A.5. Results Wilcoxon rank-sum test (z-statistic and P-value) regarding antimicrobial use after cluding intervention flocks one by one.

	All	−1	−2	−3	−4	−5	−6	−7	−8	−9	−10	−11	−12	−13	−14	−15
1	1.597	1.429	1.218	0.945	0.570	0.878	−0.218	NA	NA	NA	NA	NA	NA	NA	NA	NA
	(0.110)	(0.153)	(0.223)	(0.345)	(0.569)	(0.380)	(0.827)									
2	0.735	0.579	0.645	0.732	0.849	0.816	1.044	0.775	NA	NA	NA	NA	NA	NA	NA	NA
	(0.462)	(0.563)	(0.519)	(0.464)	(0.396)	(0.414)	(0.296)	(0.439)								
3	−0.954	−1.174	−1.427	−1.236	−1.011	−0.742	−0.744	−0.561	−0.108	0.000	0.794	0.402	−0.297	NA	NA	NA
	(0.340)	(0.240)	(0.154)	(0.217)	(0.312)	(0.458)	(0.457)	(0.575)	(0.914)	(1.000)	(0.427)	(0.688)	(0.766)			
4	1.768	1.936	1.714	1.601	1.461	1.279	1.549	1.000	0.000	NA	NA	NA	NA	NA	NA	NA
	(0.077)†	(0.053)†	(0.087)†	(0.109)	(0.144)	(0.201)	(0.121)	(0.317)	(1.000)							
5	−1.676	−1.758	−1.536	−1.390	−1.727	−1.574	−1.383	−1.894	−1.715	−1.470	−1.098	NA	NA	NA	NA	NA
	(0.094)†	(0.079)†	(0.125)	(0.165)	(0.084)†	(0.116)	(0.167)	(0.058)†	(0.086)†	(0.142)	(0.272)					
6	3.372	3.317	3.254	3.182	3.098	3.000	2.882	2.739	2.558	2.324	2.000	1.500	NA	NA	NA	NA
	(0.001)**	(0.001)**	(0.001)**	(0.002)**	(0.002)**	(0.003)**	(0.004)**	(0.006)**	(0.011)*	(0.020)*	(0.046)*	(0.134)				
7	−0.201	−0.325	−0.589	−0.387	−0.429	−0.641	−0.365	−0.640	−0.775	−1.333	−1.000	NA	NA	NA	NA	NA
	(0.841)	(0.745)	(0.556)	(0.699)	(0.668)	(0.522)	(0.715)	(0.522)	(0.439)	(0.182)	(0.317)					
8	−1.586	−1.641	−1.545	−1.521	−1.585	−1.659	−1.535	−1.389	−1.214	−1.286	−1.056	−1.134	−1.254	0.293	0.218	NA
	(0.113)	(0.101)	(0.122)	(0.128)	(0.113)	(0.097)†	(0.125)	(0.165)	(0.225)	(0.199)	(0.291)	(0.257)	(0.210)	(0.770)	(0.827)	
9	−0.037	−0.039	0.206	0.219	0.328	0.654	0.597	0.531	0.582	0.787	0.722	0.640	0.535	−2.324	−2.000	−1.500
	(0.971)	(0.969)	(0.837)	(0.826)	(0.743)	(0.513)	(0.551)	(0.596)	(0.561)	(0.431)	(0.470)	(0.522)	(0.593)	(0.020)*	(0.046)	(0.134)
10	0.735	0.811	1.119	1.308	1.183	1.042	0.878	1.323	1.157	1.342	1.143	0.893	0.378	−0.570	−1.171	−1.528
	(0.462)	(0.418)	(0.263)	(0.191)	(0.237)	(0.298)	(0.380)	(0.186)	(0.247)	(0.180)	(0.253)	(0.372)	(0.706)	(0.569)	(0.242)	(0.127)
11	3.334	3.240	3.130	3.000	2.842	2.646	2.393	2.049	1.528	NA	NA	NA	NA	NA	NA	NA
	(0.001)**	(0.001)**	(0.002)**	(0.003)**	(0.005)**	(0.008)**	(0.017)*	(0.040)*	(0.127)							
12	1.470	1.157	1.678	1.610	1.359	1.225	1.567	1.162	NA	NA	NA	NA	NA	NA	NA	NA
	(0.142)	(0.247)	(0.093)	(0.107)	(0.174)	(0.221)	(0.117)	(0.245)								
13	0.794	1.157	1.086	1.571	2.030	2.646	2.393	2.049	1.528	NA	NA	NA	NA	NA	NA	NA
	(0.427)	(0.247)	(0.277)	(0.116)	(0.042)*	(0.008)†	(0.017)*	(0.040)*	(0.127)							
14	0.105	0.116	0.129	0.146	0.170	0.204	0.261	0.000	NA	NA	NA	NA	NA	NA	NA	NA
	(0.916)	(0.908)	(0.897)	(0.884)	(0.865)	(0.838)	(0.794)	(1.000)								
15	−1.857	−2.030	−1.890	−1.709	−1.464	−1.091	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	(0.063)†	(0.042)*	(0.059)†	(0.087)†	(0.143)	(0.275)										
16	−0.040	0.254	−0.045	0.098	0.265	−0.116	0.319	0.857	1.543	1.323	0.798	0.000	−1.528	NA	NA	NA
	(0.968)	(0.800)	(0.964)	(0.922)	(0.791)	(0.908)	(0.749)	(0.391)	(0.123)	(0.186)	(0.425)	(1.000)	(0.127)			
17	0.772	0.578	0.533	0.866	0.630	0.579	1.162	0.878	0.849	0.612	0.522	0.387	NA	NA	NA	NA
	(0.440)	(0.563)	(0.594)	(0.387)	(0.529)	(0.563)	(0.245)	(0.380)	(0.396)	(0.540)	(0.602)	(0.699)				
18	1.852	1.620	1.342	1.000	0.568	1.134	0.570	1.171	0.218	NA	NA	NA	NA	NA	NA	NA
	(0.064)†	(0.105)	(0.180)	(0.317)	(0.570)	(0.257)	(0.569)	(0.242)	(0.827)							
19	−1.278	−0.940	−0.490	−0.745	−0.387	−0.293	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	(0.201)	(0.347)	(0.624)	(0.456)	(0.699)	(0.770)										
20	0.463	0.447	0.286	0.568	0.945	1.026	1.171	0.218	NA	NA	NA	NA	NA	NA	NA	NA
	(0.643)	(0.655)	(0.775)	(0.570)	(0.345)	(0.305)	(0.242)	(0.827)								

$^{\dagger}P \leq 0.10$, $^{*}P \leq 0.05$, and $^{**}P \leq 0.01$.

Table A.6. Overview used equations in the gross margin analysis.

Description	Equation
Total feed used by delivered animals (kg)	$\left(\frac{\text{Cycle duration} \cdot FCR \cdot ADG}{1{,}000}\right) \cdot \text{number of broilers slaughtered}$
Total revenue	$\text{Mean weight} \cdot \text{number of animals slaughtered} \cdot \text{producer price}$
Total feed costs	$(\text{Total feed used by delivered animals} \cdot \text{feed price per kg}) + \left(\frac{\left(\frac{\text{cycle duration} \cdot FCR \cdot ADG}{1{,}000}\right) \cdot (\text{number of animals slaughtered} - \text{number of animals at set} - \text{up})}{2} \cdot \text{feed price per kg}\right)$
Total costs day-old chicks	$\text{Number of day} - \text{old chicks at set} - \text{up} \cdot \text{day} - \text{old chick price}$
Total feed profit	$\text{Total revenue} - \text{total feed costs} - \text{total costs day} - \text{old chicks}$
Total other variable costs	$\text{Number of day} - \text{old chicks at set} - \text{up} \cdot \text{other variable costs per day} - \text{old chick}$
Gross margin	$\text{Total revenue} - \text{total feed costs} - \text{total costs day} - \text{old chicks} - \text{total other variable costs}$
Gross margin per 10,000 animals at set-up	$\frac{\text{Gross margin}}{\text{Number of day} - \text{old chicks at set} - \text{up}} \cdot 10{,}000 \text{ day} - \text{old chicks at set} - \text{up}$

Table A.7. Overview of interventions.

Problem	Number of actions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Animals	**61**																				
Coccidiosis	**36**																				
Burning floor	2		1																	1	
Cleaning with soda	2													1							1
Improve diagnostics—systematic OPG's	8					1	1			1	1	1					1	1		1	
Optimize Anticoccidial rotation program	11	1				1	1	1		1	1	1	1	1			1			1	
Phytoproducts	3		1											1		1					
Systematic coccidiosis scoring	5							1					1		1		1	1			
Vaccination coccidiosis	5		1	1					1									1			1
Enteritis	**16**																				
Improved diagnostics, lesions scoring by Vet	7			1	1			1	1	1					1	1					
Phytoproducts	4	1												1				1	1		
Probiotics	5			1	1					1									1		1
Immunity	***7***																				
Improve vaccination protocol	2											1								1	
New vaccination schedule based on serology	5		1				1							1	1	1					
Respiratory problems	***2***																				
Improved diagnostics: serology/PCR	1							1													
Weekly disinfection with Halamid spray	1							1													
Farmer	**23**																				
Monitoring	**9**																				
Close follow up first week D0-D1-D7	9			1	1				1	1			1		1	1	1	1			
Training farmer	**14**																				
Education with "Poultry-Signals"	6		1	1					1	1		1						1			
Measure weight, climate D1	7			1	1			1	1				1		1	1					
Optimize chick feeding	1																				1
Farm	**35**																				
Climate	**4**																				
Audit by specialist and new schedules	4		1							1			1					1			
Feed	**16**																				
Feed additives -prebiotic, probiotic, acids	10		1			1	1	1		1					1	1		1	1		1
New feed mill	6		1												1	1		1	1		1
Hygiene	**2**																				
Cleaning by specialized company	1														1						
Separation clean and dirty area	1														1						
Litter	**2**																				
Change to peat	2		1												1						
Stocking density	**2**																				
Lower stocking density	2	1	1																		
Veterinarian	**2**																				
New vet	2											1			1						
Water quality	**7**																				
Disinfection water	5							1		1			1		1					1	
Regular water analysis	1			1																	
Separate medication reservoirs	1			1																	