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Farm-economic analysis of reducing antimicrobial use whilst adopting improved management strategies on farrow-to-finish pig farms

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Highlights:

- The present study assesses the farm economic impact of reducing antimicrobial usage
- A quasi-experimental study design is the general approach
- Propensity score matching is performed to estimate reliably the effect of the management intervention on the technical parameters
- Reduction on antimicrobial usage can be achieved without hampering the enterprise profit
- These results can be used by stakeholders to incentivize farmers to reduce their antimicrobial usage

Abstract

Due to increasing public health concerns that food animals could be reservoirs for antibiotic resistant organisms, calls for reduced current antibiotic use on farms are growing. Nevertheless, it is challenging for farmers to perform this reduction without negatively affecting technical and economic performance. As an alternative, improved management practices based on biosecurity and vaccinations have been proven useful to reduce antimicrobial use without lowering productivity, but issues with insufficient experimental design possibilities have hindered economic analysis. In the present study a quasi-experimental approach was used for assessing economic impacts of reduction of antimicrobial use coupled with improved management strategies, particularly biosecurity strategies. The research was performed on farrow-to-finish pig farms in Flanders (northern region of Belgium). First, to account for technological progress and to avoid selection bias, propensity score analysis was used to compare data on technical parameters. The treatment group (n=48) participated in a intervention study whose aim was to improve management practices to reduce the need for and use of antimicrobials. Before and after the change in management, data were collected on the technical parameters, biosecurity status, antimicrobial use and vaccinations. Treated farms were matched without replacement with control farms (n=69), obtained from the Farm Accountancy Data Network, to estimate the difference in differences (DID) of the technical parameters. Second, the technical parameters' DID, together with the estimated costs of the management interventions and the price volatility of the feed, meat of the finisher pigs, and piglets served as a basis for modelling the profit of 11 virtual farrow-to-finish pig farms representative of the Flemish sector. Costs incurred by new biosecurity measures (median +€3.96/sow/year), and new vaccinations (median €0.00/sow/year) did not exceed the cost reduction achieved by lowering the use of antimicrobials (median -€7.68/sow/year). No negative effect on technical parameters was observed and mortality of the finishers was significantly reduced by -1.1%. Even after a substantial reduction of the antimicrobial treatments, the difference of the enterprise profit increased by +€2.67/finisher pig/year after implementing the interventions. This result proved to be robust after stochastic modelling of input and output price volatility. The results of this study can be used by veterinarians and other stakeholders to incentivise managers of farrow-to-finish operations to use biosecurity practices as a cost-effective way to reduce antimicrobial use.

Keywords: antimicrobial usage, biosecurity, farrow-to-finish pig farms, farm-economic analysis, propensity score matching, longitudinal design

1. Introduction

The extensive use of antimicrobials by the pig industry (Dunlop et al., 1998; Callens et al., 2012; DANMAP, 2013; European Medicines Agency, 2013; Filippitzi et al., 2014; MARAN, 2014; Rushton et al., 2014) is linked to the selection and spread of resistant bacteria which may be transferred across species through direct or indirect contact (Schwarz et al., 2001; Aarestrup, 2005; Chantziaras et al., 2014).

According to the most recent ESVAC report (European Medicines Agency, 2014), in 2012 Belgium was ranked 6th out of 25 countries in the EU in terms of sales volume of antimicrobials for food producing animals. The majority of the aforementioned agents were used in pork production (Filippitzi et al., 2014), suggesting that targeting the pig sector may be the fastest way for Belgium to reduce the use of these agents (Filippitzi et al., 2014). Unfortunately, recent reports of antimicrobial surveillance in Belgium have shown that after three consecutive years of reduced usage in food production animals, the consumption of such agents in 2014 again increased by 1.3% in comparison with 2013 (BelVet-SAC, 2011, 2012, 2013, 2014). This slight increase in the consumption of antimicrobial agents occurred despite the endeavours of the Centre of Expertise on Antimicrobial Consumption and Resistance in Animals (AMCRA), whose guidelines are encouraged to be used by Belgian veterinarians to aid their judicious prescription of antimicrobial agents. Those guidelines state that antimicrobials cannot be used as substitutes for good hygiene, housing, and appropriate feed. Farmers do not always concur, seeing prophylactic antimicrobial treatments as an easier, cheaper and less labour-intensive way to prevent conditions and thus guarantee the productivity parameters (and by extension, the farm's financial situation) than either therapeutic treatments (Callens et al., 2012) or investments in infrastructure or disinfection of the farm (Filippitzi et al., 2014). Dutch qualitative research (Speksnijder et al., 2015) confirmed the complexity of the decision to administer prophylactic treatments with respect to other operational (e.g. buying lower cost feed or less nutrient-dense) and strategic (e.g. labour and investment) decisions on the farm.

The relationship between the use of antimicrobials and higher productivity parameters is described in literature, but these estimations are highly variable and dependent upon farming conditions. As early as the 1950's, farming conditions have been shown to be inversely related to the productivity response to antimicrobials (Coates et al., 1951; Hill et al. 1953; Lillie et al., 1953). Moreover, a review article has demonstrated that antimicrobials have less influence on the technical parameters under optimized general production conditions (Hays, 1977). Suboptimal farming conditions, such as feeding with less tailored rations during the growing/finishing phase (Miller et al., 2003), high stress caused by animal movement (Hays, 1977), or poor hygienic conditions on the farm where pigs carried a high load of disease agents (Zimmerman, 1986) are related with higher productivity when antimicrobials were administered. These studies were frequently commissioned by manufacturing and feed industries (Thomke et al., 1998; Teillant et al., 2015) and were performed prior 2000 (Coates et al., 1951; Hill et al., 1953; Lillie et al., 1953; Hays et al., 1977; Zimmerman et al., 1986; Rosen, 1995; SOU, 1997; Thomke et al., 1998). The latter coincides with the moment when some antimicrobials growth promotors were banned in some European countries, after increased concerns and awareness about the selection of resistant bacteria, which finally led to a total phase out of such growth promotors in 2006. Studies performed after 2000 revealed that the effect of antibiotics on the productivity were lower that those of the early trials (Dritz et al., 2002; Miller et al., 2003; Graham et al., 2007; Key and McBride, 2014; Ramirez et al., 2015; Teillant et al., 2015). Current production conditions in Europe and most of the developed countries have substantially improved in the last decades thus it is questionable whether the effect of antimicrobials on productivity will remain high (Rushton et al., 2015). Data on the impact on productivity after the ban on antimicrobial growth promotors in Europe are limited, although available data from Sweden and Denmark suggest that restricting the use of growth promotors is possible with only minimal production consequences (Wierup, 2001; WHO, 2003; Aarestrup et al., 2010).

The adoption of general herd management strategies (e.g. biosecurity practices or specific vaccinations) may be a more sustainable alternative to prophylactic use of antimicrobials (Postma et al., 2015a). Moreover, higher levels of biosecurity are associated with improved average daily weight gain, better feed conversion ratio and decreased consumption of antibiotics (Laanen et al., 2013). Alonso et al. (2013a, 2013b) found that farrow-to-wean pig farms with an air filtration system combined with standard biosecurity measures had a significantly higher farrowing index which translated into more piglets weaned per sow per year and reduced sow mortality. The farmers' main objection to implementing these new strategies appears to be financial (Visschers et al., 2015). Among pig farmers in the UK, Fraser et al. (2010) found a clear inverse relationship between the willingness to adopt biosecurity practices and their estimated costs. Veterinary service providers also feel a need to provide more proof about the potential economic consequences of proposed farm biosecurity practices (Gunn et al., 2008). Farmers have shown interest in knowing the costs of biosecurity measures, as well as their potential benefits (Laanen et al., 2014), but the lack of insight still limits implementation. Detailed information about the economic impact of alternatives to antimicrobials could foster awareness but to date only few studies have evaluated such expenses. Two cross-sectional studies which also accounted for the indirect economic impact due to changes in technical parameters found that farrow-to-finish pig farms exhibiting a higher biosecurity and health status were correlated with improved technical parameters and a higher economic margin of approximately €180/sow/year (Corrégé et al., 2011) and €200/sow/year

(Corrégé et al., 2012) than the farms with the lowest biosecurity status. The methodological weakness of these studies (e.g. the lack of a control group and their cross sectional nature) may have overestimated that effect. A longitudinal study could compensate for these weaker methodologies.

In the present study, we used a quasi-experimental approach to assess the economic impact of substituting improved management practices, particularly biosecurity strategies, for antimicrobial use. Farrow-to-finish pig farms (n=50) were recruited to participate in a longitudinally-designed research project, during which the farms adopted specific tailored advice concerning biosecurity strategies, general herd management, and vaccination schemes together with a simultaneous decrease in the administration of antimicrobial drugs. The direct costs incurred by the strategies adopted were estimated and the resulting benefits were assessed with an input-output stochastic production economic model.

2. Material and Methods

The overall approach was a quasi-experimental design (Harris et al., 2006) in which treated farms were matched using propensity scores (PS) (Dehejia and Wahba, 2002) with control farms. The control farms were selected from the Flemish Farm Accountancy Data Network (FADN)[1], an instrument for evaluating the income of agricultural holdings and the impacts of

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[1] The FADN performs an annual survey via a liaison agency in each Member State of the European Union. Physical, structural, economic, and financial data are collected from a representative sample of the agricultural commercial holdings in the European Union (European Commission, 2015).

the Common Agricultural Policy. The treated farms received tailored advice to implement a management intervention (MI) which consisted of measures to improve biosecurity, general management, vaccination and reduction of antimicrobial usage. Technical parameters of pig production were recorded before and after the advice was given. To account for the technological progress of the pig production and reduce selection bias propensity score matching (PSM) was used. The outcome of the PSM is a difference in differences (DID) which is a treatment effect attributable to the MI. Secondly, the DID of the technical parameters served as input data in a farm production economic input-output model whereby differences in enterprise profit after versus before having adopted the MI were calculated. Besides these differences in technical performance, direct economic effects of the MI were determined using a cost accounting analysis based on interviews with farmers and various databases for prices and purchase costs which were also fed into the farm production economic model. To account for the heterogeneity in the pig farming population, the economic input-output model was simulated for 11 virtual representative farms which are theoretical constructions based on the full FADN sample of farrow-to-finish pig farms in Flanders for the years 2010, 2011 and 2012.

2.1.Data collection on treated farms

The ‘reduction of antimicrobials project’ recruited 65 operational Flemish pig farms. These farms received guidance to reduce antimicrobial usage while optimising herd health management, mostly through improvements to farm biosecurity. Of the 65 participating farms, 50 were farrow-to-finish pig farms which were used for the economic evaluation study. Of the 50 treated farms, 48 remained under study during the entire study period. One farm withdrew for family reasons, and another was removed from the dataset because the finisher operations ceased before the third visit. The typical stages of production in farrow-to-finish pig farms in

Belgium are breeding, gestation, farrowing, nursery, growing, and finishing, which can occur at one or more locations. Of the 48 treated farrow-to-finish pig farms, 8 were multi-site. In the remaining 40 farms, all production stages occurred at the same site. The mean weaning age for the treated farms at the first visit was 23.2 days (SD=2.6) and 22.8 days (SD=2.6) at the third visit. For the control farms, the mean weaning age was 25.9 (SD= 4.5) in 2011 and 25.8 days (SD=4.6) in 2012. The treated farms were visited 3 times between December 2010 and May 2014. On average 8 months elapsed between the first and second visit (mean=8.59, SD=6.50), and 8 months passed between the second and third visit (mean=8.20 SD=2.51). During the first visit, data on specific aspects of health management like the vaccination scheme used, characteristics of anthelmintic therapy, and diagnostic testing were collected. Data on antimicrobial usage and biosecurity status were also obtained. The biosecurity status of the farms was assessed using Biocheck.UGent®. This risk-based weighted scoring system provides an objective evaluation of the biosecurity status of a pig farm, accounting for both internal and external biosecurity. The system consists of a series of surveys. The results of the questionnaires are a risk-based weighted score expressed from 0 to 100 that indicate the farm biosecurity status (Laanen et al., 2010, 2013; Postma et al., 2015). Data on the antimicrobial usage was translated into a treatment incidence using the ABcheck.Ugent® calculation system (Postma et al., 2014; Timmerman et al., 2006). The questionnaires can be obtained upon request from the corresponding author. Data on technical performance were obtained through face-to-face surveys with the farmers using 2 technical parameters from the farrowing stage, litter size (LS) (number of piglets born alive per year) and farrowing index (FI) (number of farrowings taking place in a year or numbers of litters per sow per year) and 2 technical parameters from the finishing stage, average daily weight gain (ADWG) and mortality of the finishers (MF). The farmers obtained these data through their accountancy and advisory service providers.

Using the information gleaned from the first visit, a tailored advice plan (the MI) was developed and disseminated to the farmers during the second visit. Examples of the recommendations concerning the improvement of general pig husbandry and biosecurity (the MI) are to change or wash the boots before entering different rooms of the farm to avoid the transmission of pathogens and cleaning and disinfecting the cadaver storage of the farm after the cadavers are collected by the rendering company. Another set of recommendations concerned reduction of the antimicrobial usage, such as minimising the use of strong, last-choice antibiotics like quinolones, 3rd and 4th generation cephalosporins and macrolides.

Compliance with the recommendations was assessed during the third and last visit, where data similar to the first visit were collected for comparison.

2.2. Propensity score matching of the control farms

We elected to use PSM with DID estimation due to the fast evolution of the swine industry and the lack of randomness in farm selection. Briefly, this PSM technique searches for farms in a database with an as equal as possible probability to be in the treatment group and matches each treated farm with such a control farm. It then estimates effect size using a DID estimation, i.e. the difference between the after versus before difference in the treated group versus the after versus before control group.

Data on 117 farrow-to-finish pig farms were obtained from the Flemish FADN dataset for 2011 and 2012. In that dataset 86 farms had records for both 2011 and 2012. In total, 69 of the 86 control farms in which data were collected on 2011 and 2012 were kept for further analysis because 17 farms were removed due to lack of records on the covariate used to match ‘building year of the oldest building'. The 69 control farms served to extract a control group with similar baseline characteristics to the treated group after computing a propensity score, whereby the conditional probability of being treated conditional on observed baseline covariates was calculated (Rosenbaum and Rubin, 1983; Austin, 2011). Those treated and control farms which shared similar values of the propensity score were matched (Rosenbaum and Rubin, 1983) and used to estimate the DID of the technical parameters. Baseline characteristics collected equally of treated and on control farms were selected to match: (i) number of sows, as a proxy of size (ii) farmer's years of experience, as a proxy of the farmer's ability and skills as a manager (Nuthall, 2009), (iii) building year of the oldest building of the farm, as a proxy of the degree of modernisation, (iv) number of employees, as a proxy for size and managerial skills of the manager of the farm (Boehlje and Eidman, 1983; Hadley et al., 2002) as well as a mere direct proxy for human capital within the farm. The implicit assumption behind this is that variables reflecting the size, the ability and skills of the farmer, and the level of modernisation influences their willingness to participate in the research project.

The analysis was conducted using the matching package (http://CRAN.R-project.org/package=Matching) for R (R development Core Team 2013) in which a one-to-one nearest neighbour matching without replacing was used. In this case, this technique selects and matches one treated farm with a propensity score closest to the control farm. Genetic matching algorithms were used because they directly optimise the covariate balance which was assessed with the two-sample t-test of the covariates. This t-test indicates whether there are significant differences in the mean of the covariates between the treated and control group (Rosenbaum and Rubin, 1983). The mean DID of the technical parameters: ADWG, FI, LS, and MF and its Abadie-Imbens standard error (SE) was estimated.

Whenever data were missing for the first or third visit for a particular farm, it was excluded from the propensity score analysis. For MF there were 16 values missing in the second, third or both visits. In total, 23 values were missing for the ADWG from the second, third or both farm visits. For the LS and FI there were 12 missing values in one of the two visits or both.

2.3. Direct net costs of the interventions

The direct net costs of applying the measures recommended during the second visit were assessed using a cost accounting analysis (Table 1). Prices on commodities (e.g. boots, gloves, disinfectant dispenser, shampoo used to shower the sows before moving to the farrowing pen, disinfectant products, etc.) were gathered from an online web shop commonly used by Belgian farmers (http://www.agrologic.be). Veterinary costs, including the analysis of samples, were obtained from Animal Health Care Flanders, a non-profit consulting organisation financed by farmers' membership fees. The time spent performing certain proposed intervention tasks (such as changing boots between departments or washing the sows with sow shampoo before farrowing) was gathered from literature, consultation with a swine veterinarian and a researcher at the Veterinary Faculty of the University of Ghent, assumptions, and common sense. This was triangulated by two of the coauthors who have extensive knowledge in this matter (for details on the assumptions see Table 1). Some purchased commodities were durable inputs, i.e. items that can be used over a period of years on the farm, and incurred fixed costs (e.g. boots, boards, brooms, disinfectant dispenser). Depreciation was accounted for using a straight line method, in which the difference of the purchase and salvage price of the item are divided by the number of useful years of its use (depreciation period) (Rushton, 2009a). The depreciation period was set at 3 years for frequently used goods (e.g., boots, overalls, brooms) and 5 years for goods that are less susceptible to wear and tear (e.g., disinfection baths for boots, disinfectant dispenser). The salvage price was assumed to be €0 for durable inputs that are frequently used while a salvage price was assumed for goods with 5 useful years, which could be obtained if the durable good is sold secondhand (Table 1).

Vaccination prices were obtained through a questionnaire sent to 2 veterinarians active in pig veterinary medicine. Those served to estimate the average price of the vaccines and were used for further calculations (Table 2). When information on the number of doses of vaccine given within a year was not available, it was assumed that sows were vaccinated once before each farrowing, gilts were vaccinated twice during the period as gilts, and live piglets were vaccinated once per year. The time to vaccinate 125 animals was considered to be 1 hour (Alarcón et al., 2013a).

Data on prophylactic antimicrobial usage on the farms were provided by the farmer, while data on curative treatments were obtained from the herd veterinarian. Further the invoices of the herd veterinarian, and/or the invoices from the feed mills on purchase of antibiotic products over the year preceding the visit were used. The number of animals treated was obtained by using the management system results for the number of sows, live born piglets, weaned piglets and finishers. In case the number of finishers could not be derived from the data, this was calculated by taking the number of weaned piglets and correcting that number based on finisher mortality. Weights of the animals were based on the standard weights proposed by ESVAC in Table A11 of their third report (European Medicines Agency, 2013). Data on antimicrobial prophylactic treatments were provided by the 48 participating farms on both the first and third visit. Data on the curative treatments were provided by 29 farms for the first and third visit. For 19 farms with missing data on the curative antimicrobial treatment on the third visit, it was assumed that the curative costs in the third visit stayed the same as in the first visit and its difference was accounted as €0/sow/year. One farm was removed from the calculation of the difference between antimicrobial costs due to a large decrease of antimicrobial costs (more than 2.5 times smaller than the minimum); including it may have unduly influenced the distribution of the reduction of the antimicrobial costs.

In total 164 different antimicrobials were used on the participating farms. Prices of 121 of them were obtained from the Large Animal Practice of Ghent University. The prices of 9 others were found in the invoice registration of the veterinarians of the participating farms and one similar farrow-to-finish pig farm that participated in a similar European study. For 24 antimicrobials for which no prices could be found, the price of a similar product (same active substance and same administration route) was used. For 10 medicated feed mixes, the average of the prices of other medicated feed products was used. To calculate the costs of the antibiotics in the first and the third visit, the prices (in €/g or €/ml) of the antibiotic used were multiplied by the mass in of grams or the volume in milliliters of antimicrobial used per animal then again multiplied by the number of animals treated. The difference in the cost of antibiotics between the third visit and the first visit was inserted into the input-output production economic model.

2.4. Description of the 11 virtual representative farms

Virtual representative farms were generated from the full FADN sample for the years 2010, 2011, and 2012. Those farms were depicted in the input/output space using efficiency analysis (Coelli et al., 2005). In particular, technical efficiency and the cost allocative efficiency were used. Technical efficiency reflects the ability of a farm to produce maximal amounts of output(s) with a given amount of input(s). Given the prices of inputs, the cost allocative efficiency can be estimated which expresses the ability to use inputs in cost minimising proportions. Both efficiency parameters permitted to find 11 virtual representative farms using the cluster procedure average linkage cluster of SAS. The definition of the typical farms was beyond the scope of this study. More information on the technical efficiency and cost allocative efficiency can be obtained in van der Voort et al. (2015). For information on the variables used to describe the 11 virtual representative farms see Table 3.

2.5. Input-output production economic model

Besides the direct costs incurred, the MI may also have indirect economic consequences due to changes in technical performance. We accounted for this by using a stochastic production-economic input-output model operationalised in Excel (Van Meensel et al., 2010).

The model estimated the enterprise profit as main economic indicator. The enterprise profit can be described as the revenues minus variables and fixed costs (Rushton, 2009b; Eq. (1)).

$$\text{Enterprise profit} = \text{Revenues} - \text{Variable} - \text{Total Fixed Costs} \qquad (1)$$

The revenues consist of the amount of output sold multiplied by their prices. In farrow-to-finish pig production the main output is the sale of kg of marketable finisher pig (Y_F) and, because some farmers may sell some of their piglets to finisher farms, the number of piglets sold (Y_P) is also an output. When prices of marketable finisher pig in €/kg living finisher pig (PY_F) and piglets in €/piglet (PY_P) are provided, the revenues can be calculated using Eq. (2):

$$\text{Revenues} = \text{PY}_\text{F} \times \text{Y}_\text{F} + \text{PY}_\text{P} \times \text{Y}_\text{P} \qquad (2)$$

By definition, variable costs vary directly with the amount of output produced, declining to zero if the produced output is zero. Traditionally, variable costs are divided into feed costs and other variable costs (Rushton, 2009b). The latter included the expenses due to the implementation of the management strategies adopted by the treated farms, e.g. purchase of disinfectants, vaccinations, veterinary costs, and antimicrobial agents. When the feed prices of the sows (PF_S), piglets (PF_P), and finishers (PF_F) are known, the variable costs induced by the purchase of feed can be calculated.

$$\text{Variable Costs} = \text{PF}_\text{S} \times \text{XF}_\text{S} + \text{PF}_\text{P} \times \text{XF}_\text{P} + \text{PF}_\text{F} \times \text{XF}_\text{F} + \text{Other Variable Costs} \tag{3}$$

Some strategies adopted by the farmers involved purchasing durable inputs that underwent depreciation (e.g. the purchase of brooms, boots, and the like) and additional labour which was valued per extra hour needed. The extra hours needed were accounted using the employee wage as an opportunity cost, following the reasoning used in European FADN (Farm Accountancy Data Network) analysis. It was assumed that the total fixed costs remained equal before and after the intervention. Only fixed costs attributable to the MI were available which allowed us to estimate the difference in enterprise profit after versus before the MI (Eq (4)) as overall economic indicator.

$$\Delta\text{Enterprise profit}_{\text{after}-\text{before}} = \text{Revenues}_\text{after} - \text{Variable costs}_\text{after} - \text{Fixed costs MI} - \text{Revenues}_\text{before} - \text{Variable costs}_\text{before} \tag{4}$$

In addition, the initial deterministic simulation model was also customised into a Monte-Carlo-based stochastic model with @Risk 6.0 (Palisade Corporation, California) which allowed 2 types of stochasticity to be inserted. The first type reflects price volatility of the input and output prices: PF_S (€/kg), PF_P (€/kg), and PF_F (€/kg), PY_F (€/kg), and PY_P (€/piglet). Data on the monthly volatility of the feed prices were obtained from the Flanders Department of Agriculture and Fisheries (Department of Agriculture and Fisheries, Government of Flanders) for 2010, 2011 and 2012. Likewise, historical monthly prices of finishing pigs and piglets were obtained from a Belgian feed company for the years 2010 (Anonymous, 2010), 2011 (Anonymous, 2011), and 2012 (Anonymous, 2012) (Figure 1). The lowest, average and highest input (PF_S, PF_P, PF_F) and output prices (PY_F and PY_P) obtained from the historical monthly data served to model with Beta Pert distributions the price volatility of the prices of inputs and outputs of the 11 virtual representative farrow-to-finish pig farms. The statistical dependence between the 5 type of prices (PF_S, PF_P, PF_F, PY_F, PY_P) was measured by the Pearson correlation coefficient (ρ) which is defined as the covariance of 2 variables divided by their respective standard deviations. Similarly as in Niemi et al. (2011), monthly data of the feed prices (Department of Agriculture and Fisheries, Government of Flanders, 2016) and for the finishers and piglet prices (Anonymous 2010; 2011; 2012) of the Flemish market (Figure 1) served to estimate the Pearson correlation coefficients. In total 10 different Pearson correlation coefficients were estimated (Table 3). For instance, the correlation between correlation between PF_P and PF_S was estimated with Eq. (5).

$$\rho = \mathrm{corr}\ (\mathrm{PF_P}, \mathrm{PF_S}) = \frac{\mathrm{cov}\ (\mathrm{PF_P}, \mathrm{PF_S})}{\mathrm{SD}\ (\mathrm{PF_P})\ \mathrm{x}\ \mathrm{SD}\ (\mathrm{PF_S})} \tag{5}$$

Only significant Pearson correlation coefficients were taken into account; those informed the correlation matrix (Table 3). This correlation matrix was inserted into the stochastic input-output production economic model with the @Risk command RiskCorrmat.

The second type of stochasticity we accounted for was the uncertainty regarding the treatment effect on the technical parameters and regarding the direct net costs of the treatment. The PSM with DID estimation of the ADWG (g/day), FI (number of farrowings/year), LS (number of piglets born alive/year) and MF (%) yielded a mean and Abadie Imbens SE as measurement of the average treatment effect on the treated farms. Both the mean and the Abadie-Imbens SE were used to inform a normal distribution with @Risk in the stochastic input-output production economic model. Another stochastic distribution was fitted using the data of the MI costs to account for the heterogeneity of the changes in direct costs across the treated farms.

Simulations were used to estimate the effect on the enterprise profit in 11 virtual representative Flemish farrow-to-finish pig farms due to the change in the technical parameters and direct costs. The simulation started from the situation of the farm before the MI and compared it to the simulated situation after the MI was implemented. The final model was run with 1,000 Monte Carlo Markov Chain iterations for each of the 11 virtual representative Flemish farrow-to-finish pig farms. The mean, standard deviation and 95% confidence interval of the $\Delta \text{Enterprise profit}_{\text{after}-\text{before}}$ were estimated in €/sow/year, €/average present finisher pig/year, and €/finisher pig/year.

3. Results

3.1. Descriptive statistics

Treated farms had on average more sows than control farms (301 vs 175) before matching. The covariates farmers' years of experience, building year of oldest building, and number of employees had similar values on treated and on control farms (Table 5).

3.1.1. Technical parameters

At baseline level, treated farms showed a slightly higher FI, LS, and MF than control farms. After the third visit, treated farms showed an improved LS, ADWG and MF (Table 6). The control farms did not show any differences when comparing the year 2012 to the year 2011.

3.2. Propensity score analysis

Table 7 presents the DID of the ADWG, FI, LS and MF between treated and control farms and between the second and third visit as obtained with genetic propensity score matching. Matching resulted in 50 observations to estimate the DID of the ADWG (25 treated farms were automatically matched to 25 control farms out of the 69 control farms with the R function matching). Similarly, matching resulted in 72 observation pairs for the estimation of the DID of FI and LS. Finally, matching resulted in 64 observation pairs to estimate the DID of MF. The mortality of the finishers was significantly lower on treated farms than on control farms (mean -1.1%, P-value: 0.03).

Propensity score matching is consistent only if matching on the PS asymptotically balances the observed covariates (Diamond and Sekhon, 2013). Therefore, when propensity score matching is performed, it is important to assess that the distribution of covariates are similar after matching to an estimated propensity score. Hence, the maximum discrepancy should be small. In other words, the smallest P-value must be large (Sekhon, 2011). Table 8 shows that propensity score matching of the treated and control farms did not increase the difference between the covariates used to match based on the t-test P-values, and consequently the estimated propensity score is not biased, nor is the estimated DID. Moreover, PSM increased the balance of the covariate 'number of sows' between the treated and control group, meaning that there was less difference between the abovementioned covariate after the matching than before the matching.

3.3. Direct net costs of the interventions

The median of the total direct net costs on the treated farms was reduced by -€2.68/sow/year between the second and the third visit (Figure 2). This was mainly caused by a reduction in antimicrobial use, especially the prophylactic treatments administered to the piglets (Postma and Dewulf, 2013). This led to a cost reduction of median -€7.68/sow/year, with a large variation between farms. Increased biosecurity and more vaccinations resulted respectively in higher costs of mean €4.76/sow/year (median €3.96/sow/year) and €5.94/sow/year (median €0.00/sow/year) which had a smaller variation than the cost reduction of antimicrobial usage (Figure 2).

3.4. Enterprise profit

When volatility of prices was not modelled, farms presented on average +€107.47/sow/year higher difference of enterprise profit after the antimicrobial use was reduced than before (Table 9). Furthermore, for 4 out of 11 typical farms the 95% CI was always positive. When the price volatility was accounted for, the difference of the enterprise profit after vs. before the MI was on average lower than when volatility was not modelled, but remained positive at +€2.67/finisher pig/year or +€42.99/sow/year (Table 10).

4. Discussion

In this study the MI yielded a reduction in net direct costs between the third and the first visit, which was mostly due to a reduction of the usage of prophylactic treatment for the piglets (Postma and Dewulf, 2013). This implies that prophylactic treatments entail high costs (Figure 2). This corroborates the results of a cross-sectional study that estimated the costs of preventive measures on Finnish poultry farms where the preventive medicine costs (incurred mainly by the use of coccidiostats in broiler feed to control coccidiosis and the use of a product to prevent intestinal problems in newly hatched chicks) were the chief constituent of the preventive costs (Siekkinen et al., 2012). In our study, the use of antimicrobials was replaced by the implementation of management strategies, namely biosecurity and additional vaccinations. Our analysis suggests that the additional costs were lower than the eliminated costs associated with a reduction of antimicrobial use (Fig. 2). The impact of the yellow card in Denmark[2] on meat inspection lesions in finisher pigs was investigated by Alban et al. (2013). The authors used official Danish data on the use of antimicrobials, vaccines, and meat inspection reports. Overall, the consumption of antimicrobials was reduced without worsening the level of animal health or welfare. Moreover, the use of vaccinations increased for both gastro-intestinal syndromes and respiratory diseases. However, there was an increase in the short-term prevalence of specific lesions in the intestinal tract such as chronic enteritis, umbilical hernia, and chronic peritonitis. On the other hand, specific respiratory lesions were significantly reduced which the authors

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[2] A scheme which was adopted by the Danish Veterinary and Food Administration in 2010 which imposed restrictions on pig farmers who employed more antimicrobials than twice during the nine-week moving average in three age groups: (i) piglets/sows, (ii) weaners, (iii) finishers.

hypothesise to be one of the reasons for the lower prevalence of chronic pneumonia. Nevertheless, Alban et al. (2013) could not provide an assessment on the impact on productivity of the meat with a yellow card. In a review on the use of antimicrobials in livestock, Aarestrup (2015) showed that the restrictions on antimicrobial use imposed after the introduction of the yellow card in Denmark had very limited effects on piglet mortality, mean number of pigs produced per sow per year, average daily weight gain, and mortality rate in weaning and finishing pigs. However, the analysis of the data was based on mean values for the entire Danish pig industry. As a consequence, all the negative and positive impacts for individual pig farms may have been obscured by that analysis. Results from a recent randomised clinical trial which examined the value of using antimicrobial metaphylaxis to control the porcine respiratory disease complex demonstrated that the efficacy of administering antimicrobial metaphylaxis in finishing pigs was limited to those with lowest starting weight, and even then the costs of the antimicrobials surpassed the benefits entailed due to improved productivity levels (Ramirez et al., 2015). Our results suggest that despite the farmers' general perception (Callens et al., 2012; Speksnijder et al., 2015), antimicrobials are not necessarily cheaper than investments to improve on-farm management. The results of this study can be used by veterinarians to incentivise pig farmers to reduce their current use of antimicrobial treatments and to shift to use more sustainable practices like biosecurity strategies or vaccinations.

In general, farmers were advised based on the specific problems in their herds to reduce their antimicrobial use and to improve their biosecurity status and not only to improve a specific health problem in the farm. Other herd management changes such as adjustments to the vaccination scheme were herd-specific and targeted the herd-specific health problems as (historically) diagnosed. A recent publication showed a higher biosecurity level (internal and external) was associated with a lower frequency of treatment (against 5 symptoms) as proxy for disease incidence (Postma et al., 2015b). This suggests that biosecurity is a tool for disease prevention (Postma et al., 2015b). Treatment incidence was used to account for the different antibiotic compounds, duration of treatment, potency of the antimicrobial drug used. In the current study the treatment incidence was reduced by 52% from birth till slaughter (Postma et al., 2016 submitted publication). Specific data on changes on biosecurity practices and vaccinations, as well as more detailed information on the antimicrobial products used can be found in the supplementary files of Postma et al. (2016 submitted publication).

Biosecurity status in the treated herds was measured before and after the advice was provided using the Biocheck.UGent.be® questionnaire. Farmers were given a period of time to implement the strategies before the third herd visit. It is possible that some farmers implemented the advised strategies just before the third visit took place, underestimating the effect on the technical parameters. Data on the exact date of implementation of the measures were not available. However, in the authors' opinion, farmers may have implemented the measures shortly after the second visit as well, because they did not know the precise date of the third visit, which was scheduled according to their availability and convenience. In contrast, the substantial amount of time that elapsed between the second and third visit (average of 8 months) may have hampered the implementation of the strategies during the whole period. Indeed, changing to new practices that hinge on behavior and habits (e.g. washing hands, changing clothes and boots between rooms, etc.) appeared to be very challenging to establish as fixed routines (Racicot et al., 2012). Although a further follow-up of the herds over a longer period and with more herd visits was desirable to be able to follow the evolution of the compliance of the suggested interventions, it was not possible within the scope of this study and should thus be seen as a limitation of the study. Nevertheless, several arguments make us believe that the application and compliance of the measures were assessed in a relatively accurate manner. First, during the first visit the investigator followed the farmer without commenting, only applying precautionary measures (e.g. washing hands, changing boots between rooms, etc.) upon the farmer's request. Moreover, the Biocheck.UGent® questionnaire was only filled out after completing the herd visit, thus eliminating any possibility of the actual on-farm practices being misrepresented. Further, for approximately 75% of the Biocheck.UGent® questions and vaccination schemes, compliance could also be visually checked or validated by documentation. Second, there were no incentives nor punishments for high or low biosecurity status. The farmers therefore had no strong motivation to make biosecurity look better than it actually was. Finally, we also observed that many of our suggestions to improve the biosecurity were not implemented (as described in detail in Postma et al., 2016, submitted). The reason behind not implementing some of the pieces of advice were openly discussed with the investigator who performed the visits.

Three types of mortalities can occur in farrow-to-finish pig production i) mortality until weaning age (MTW), i.e. from birth till weaning age, ii) mortality in the nursery period, i.e. after weaning till the finishing period starts, and iii) mortality in the finishing period, i.e. from the beginning of the finishing period till slaughter age. In our study, only the mortality in the finishing period was comparably measured in both the treated and control farms. With regards to the mortality before finishing (i.e. from birth to end of nursery period) we had only data on MTW on the treated farms. For the control farms, data were available on mortality from birth to the end of the nursery period. Treated farms (n=44) presented a reduction of -0.05% (P-value = 0.9) of the MTW after the MI was implemented. Control farms (n=69) presented in 2012 an increase of +0.18% (P-value = 0.17) compared to 2012 in the mortality from farrowing to the end of the nursery. A comparison between the evolutions of the MTW of the treated farms and the mortality of the piglets from farrowing till end of nursery on the control farms helped us make a sound assumption that the DID of mortality in the piglet period was zero as included into the economic analysis. However, as described above, the data of the treated farms did not capture any elevation in the mortality during the nursery period; this represents an important limitation of the present study.

The partial lack of data on therapeutic antimicrobial usage for the third visit (n=19 farms) is also a limitation of the study. Data on curative treatments were provided by the herd veterinarians who were sometimes reluctant to make an effort to provide this information, especially when they were asked for the second time during the third herd visit. Information on prophylactic treatments was received directly from the farmers, who showed undiminished motivation to participate and provide data. Nevertheless, in the 29 herds with complete data on the curative treatments, a reduction of curative antimicrobial use was seen; the treatment incidence, expressed as defined daily doses animal (DDDA), was reduced by 52% (Postma et al., 2016, submitted publication), and its mean associated costs were reduced by 12.21%. We assumed that in the herds with missing data on the curative treatments, it was unlikely that there would have been a shift from prophylactic to curative treatments. Thus, to estimate the difference on the costs of the curative treatments between the third and the first visit for the 19 farms which had missing data on the curative treatments on the third visit, it was assumed that the curative treatment costs at the third visit stayed equal as in the first visit, and therefore its difference was counted as €0/sow/year.

The average Flemish farrow-to-finish pig farm exhibited better parameters in 2011 (ADWG=659.90 g/day, MF=3.30%, FI=2.20 farrowing/sow/year, LS=12.20 living piglets/sow/year) and 2012 (ADGW=652.80 g/day, MF=2.90%, FI= 2.30 farrowing/sow/year, LS=12.40 living piglets/sow/year) (Vrints and Deuninck, 2014) than our control farms, but worse than the treated farms (Table 6). This may have been caused by selection bias, in which participants who are the forerunners in the reduction of antimicrobial usage. They may therefore have had higher production technical parameters and may have been more prone to participate in such a project. We accounted for this by computing a propensity score and the DID, which is intended to eliminate some of the selection bias in order to estimate the attributable effect of the implemented interventions on the technical parameters. The results are in line with results of previous studies in which pig farms with higher biosecurity status were associated with better technical parameters (Corrégé et al., 2011; Laanen et al., 2013). To the authors' knowledge, the present study is one of the few in the field of animal health economics that conducts a propensity score analysis. Although this statistical technique is extensively used in agricultural economics (e.g., Mendola, 2007) and it is described for the use in veterinary epidemiology by Dohoo et al. (2009), we could only find 1 article concerned with economics of animal health in which this methodology is performed to match a treated group to a control group (Key and Mcbride, 2014). In observational studies such as the present study, in which an experiment with random allocation of treatment is cumbersome, PSM demonstrated to be especially advantageous (LaLonde, 1986; Earle et al., 2001; Mendola et al., 2007; Wu et al., 2010; Becerril and Abdulai, 2010). Propensity score analysis mimics an experimental research design using observational data with the estimation of the DID.

Before matching, the average number of sows were lower in the control farms (175) than the treated farms (301) (Table 5). Approximately 56% of Belgian farrow-to-finish pig farms have between 50 and 200 sows (FPS economics, 2013) which makes the control farms with an average number of 175 sows representative for the Belgian farrow-to-finish pig sector. Belgian farms that have more than 300 sows represent roughly 21% of the farms with sows, indicating that the treated farms did not characterize the vast majority of farrow-to-finish pig farms. As previously stated, selection bias may have been present in this study because treated farms were not randomly selected from the whole population. Despite our use of PSM as a tool to reduce selection bias, it is possible that some bias could not have been eliminated from our analysis. Caution is therefore advised when extrapolating the results of this study to other situations or countries with different farm sizes.

In literature there is no consensus about which covariates should be included in the PS model. Austin (2011) defined 4 kinds of variables that could be included into the PS model: (i) all the measured variables, (ii) all baseline covariates which are associated with treatment assignment, (iii) all covariates which affect the outcome which are denominated as potential confounders, and (iv) all covariates that affect both the treatment and the outcome or true confounders (Austin, 2011). Since the PS is the probability of treatment assignment, there are arguments to include only those variables which affect the treatment assignment. In practice it may be cumbersome to discern between true and potential confounders. For instance, in our study variables such as size of the farm may be related with both the treatment assignment (i.e. bigger farms may be more interested in participating in the study) and the outcome (i.e. bigger farms may have higher productivity and better technical parameters). According to Austin (2011), it is likely that most of the measured covariates can be safely included into the PS model. Our selection of covariates was driven by data availability for both treated and control farms. Confounders with a biological significance that may have affected the technical parameters and/or treatment assignment (e.g. the baseline health status of the farm, use of vaccinations, etc.) were not available for the control farms. This is because PSM is usually a technique that is decided upon after the initial observational study has been put in place. It has been noted that to include true and potential confounders into the PS model will yield a more precise estimate of the average treatment effect, but not less biased (Brookhart et al., 2006; Austin et al., 2007).

If balance of the covariates is achieved after PSM, there would be no associated increase in bias (Austin et al., 2011). Balance of the covariates was achieved (Table 8). As a consequence, we think that inclusion of some covariates with biological significance into the model as suggested by Austin et al. (2007) would have increased the precision of the estimates but would have not changed the measured average treatment effect. An important element of the PS analysis is the balance of the covariates which permits obtaining unbiased estimates to match control and treated farms (Rosenbaum and Rubin, 1983). In other words, the distribution of the covariates in the treated and the control farms has to be similar after the matching, which can be assessed with the t-test of the covariates between the treated and control farms. If significant differences exist between the covariates in the treated and control farms after they are matched, the result is a biased estimation of propensity score and therefore also of the DID. Our results indicated that the covariates had a better balance after matching (Table 8), supporting that the PS and consequently the DID of the technical parameters were unbiased.

With respect to the net income of pig farms, it is known that price evolutions at the time of the preparation of this manuscript were particularly adverse for farmers. At that time, feed prices were high and prices for the finishers were low. The situation has remained more or less unchanged from 2007 till the present (Anonymous, 2015). In particular, a recent report showed that the enterprise profit of the average farrow-to-finish pig farm in Flanders was -€7.30/finisher pig for 2012 (Vrints and Deuninck, 2014). The results of the present study showed that the enterprise profit yielded was positive for both the model which accounted for volatility (more realistic scenario) as well as for the model which did not account for volatility. This suggests that the results are robust, because even with volatile prices, for the 11 representative farms the enterprise profit was on average +€2.67/finisher pig/year (Table 10). Farmers who are going through a rough patch may be less willing or able to undertake cash flow funded investments to improve biosecurity status in their farm. Alarcón et al. (2013b) indicated that British pig farmers operating under disastrous economic conditions tended to delay the implementation of disease control measures. This choice contrasts with their awareness that disease negatively affects the economic situation of the farm but reaching a positive net income seems to be their most pressing priority. The need for cash leads farmers to be more thoughtful about which strategies to implement and they will appreciate the cost-effectiveness of any potential future strategy during the decision making process (Alarcón et al., 2013b). In our study, the estimated average difference in enterprise profit indicated that farms after the intervention had in average +€2.67 finisher pig/year higher enterprise profit than before the intervention (Table 10), suggesting that the reduction of antimicrobial usage and compensating it with a better biosecurity status was profitable for the farms. A cross sectional study in France including 177 farrow-to-finish pig farms estimated the biosecurity level with questionnaires tackling 400 biosecurity-related issues (Corrégé et al., 2011). Farms were divided according to three levels of biosecurity: low, average, and high. The relationship between the biosecurity level and the technical and economic parameters was estimated. The economic indicator investigated was the 'standardised economic margin' which accounted for the benefits from the sale of pig carcasses minus the costs of the feed for sows, piglets, and finishers and minus the replacement costs. The results show that farms with the highest biosecurity had a 'standardised economic margin' of €182/sow/year higher than farms with the lowest biosecurity level. Corrégé et al. (2012) also found the same trend in a similar study. However, the results of these studies are difficult to compare to those of the present study due to a number of differences. First, a different study design (cross-sectional vs quasi-experimental intervention study) and a different methodology were used to estimate the effect of the biosecurity level on the technical and the economic performance. Secondly, Corrégé et al. (2011; 2012) used the standardised economic margin which does not account for the variable costs incurred by the intervention and does take into account the costs of replacement. Third, presumably different management practices were used in the study of Corrégé et al. (2011) and our study. In addition, the average prices for 5 years (between 2004 and 2008) were used in the study of Corrégé et al. (2011) to estimate the benefits of selling the finisher carcasses. However, price volatility may considerably change the benefits of the farmers and their standardised economic margin may be overestimated.

Financial feasibility, defined as the availability of sufficient cash income to make the principal and interest payments on borrowed funds used to purchase the assets of the MI implemented, was not addressed in this study. However, if assets are purchased with money that has not been borrowed (equity) then a financial feasibility assessment is not needed (Rushton, 2009). We believe that the farmers who participated in this study did not have to borrow funds to buy the assets needed because the amounts were not very high (mean: €2,622.90/farm/year or €10.64/sow/year, median: €1,229.60/farm/year or €4.14/sow/year, minimum: €0/farm/year or €0/sow/year max: €21,944.75/farm/year or €52.78/sow/year) (Figure 2).

5. Conclusion

In this study we demonstrated that it is not only possible to reduce antimicrobial usage without sacrificing profit, but the simulation models indicate that the net profit was even higher for farms that did reduce antimicrobial usage. Because it is even more important to prove the profitability of potential changes of their management when market circumstances are adverse, the results of this study can be crucial for veterinarians and other stakeholders to incentivise pig farmers to reduce antimicrobial usage.

Conflicts of interest

None

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Previous presentation of the results

Some of the results of this paper were orally presented at the annual meeting of the Society of Veterinary Epidemiology and Preventive Medicine (SVEPM) of 2016 which was held between the16th to 18th March 2016 in Elsinore (Denmark). A shorter manuscript entitled "Farm-economic analysis of reducing antimicrobial use whilst adopting good management strategies on farrow-to-finish pig farms" was included in pages 169-181 of the Proceedings of the abovementioned SVEPM conference.

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Fig. 1. Monthly observed prices for finishers pigs, piglets and feed for finishers, for sows and piglets in Belgium in 2010, 2011 and 2012.

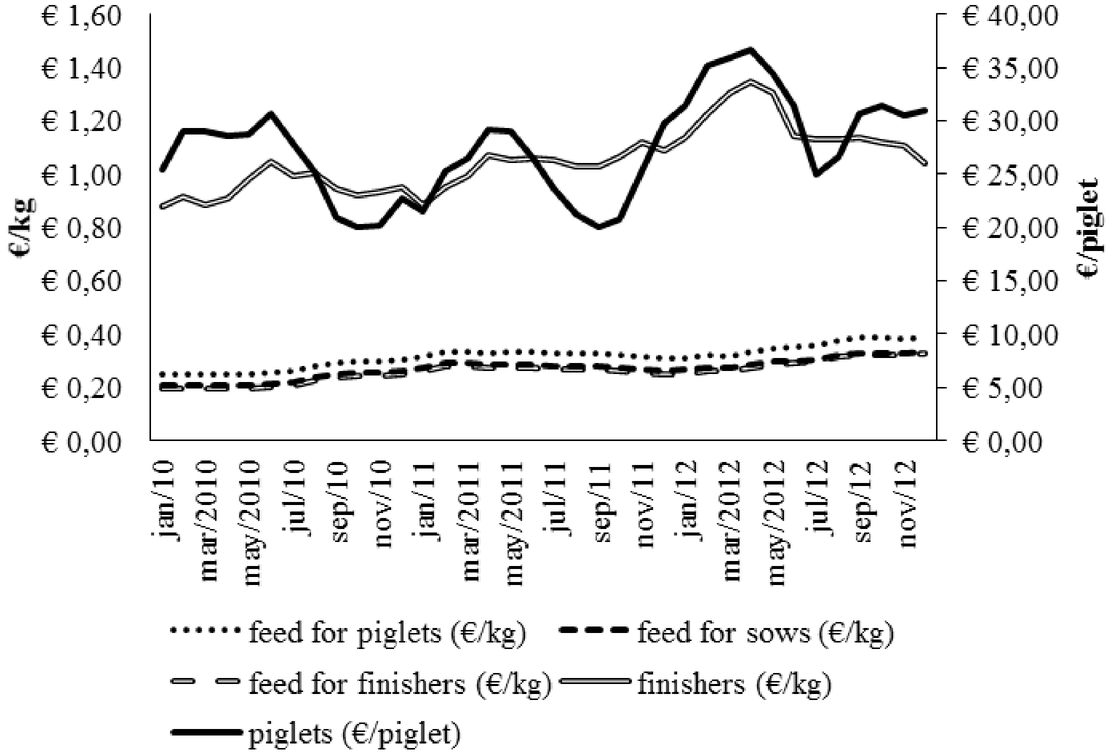
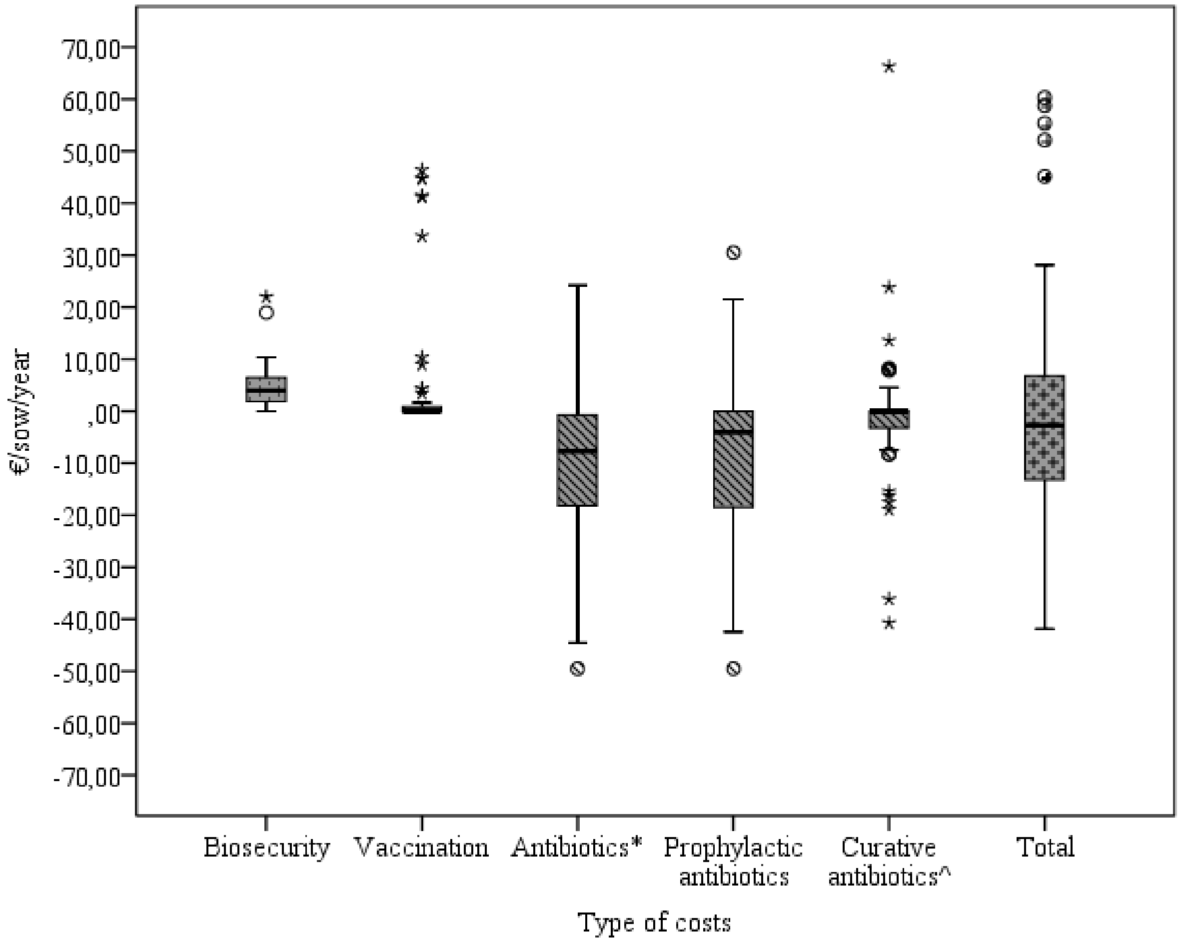


Fig. 2. Box plot of the estimated change in direct costs (€/sow/year) incurred by the 48 treated farms between the second visit and third visit as a result of the new implemented biosecurity strategies, new vaccinations and change in antibiotic use for preventive treatments and curative treatments for 47 farms.



(Legend: *one farm was removed from the antibiotic costs because it had a higher reduction on the antimicrobial usage than other farms (more than 2.5 times smaller than the minimum) which made it a far outlier and removed for the further analysis.; ^ Data on the curative treatment costs was missing on 19 farms on the third visit on which it was assumed that the curative treatment costs remained the same as in the first visit, and the difference of costs between first visit and third visit was assumed to be €0/sow/year.)

Table 1. Estimated costs of the implemented external and internal biosecurity measures

External biosecurity	Parameters	Costs (€/farm/year)	Source
All in/all-out	Creation of management plan	20.00	Assume 1 hour to create management plan. Labor cost: €20.00/ hour
Empty truck [a]	Convince transport company tc come with empty truck	20.00	Assume 5 minutes spent monthly by the farmer to convince the driver. Labor costs €20/hour
Control of visitors: shoes and clothing	Herd specific clothing for the 5 rooms[b]	100.00	Overalls cost €15 each www.agrologic.be. Assume 2 overalls for the farmer and 2 for the visitors, assume 3 years amortisation for the 5 rooms[b], with linear depreciation and no salvage price
	Herd specific shoes for the 5 rooms[b]	200.00	Price per pair of boots €30 www.agrologic.be, assume 4 pairs of boots for the 5 rooms[b], assume 3 years amortisation with linear depreciation and no salvage price
Cleaning & disinfection of cadaver storage	Weekly pick up and C/D	36.40	Assume weekly collections of cadavers, amount (70ml per cleaning) and price of a disinfectant commercial product based on a quaternary ammonium compound (price of bottle of 20l €200) www.agrologic.be
	Labor C/D	173.33	Assume 10 minutes to disinfect cadaver storage spent weekly. Labor cost: €20/ hour
Own hand hygiene	Soap, disinfectant dispenser in 5 rooms[b]	36.00	Price of dispenser €72 www.agrologic.be, assume 10 years amortisation with linear depreciation and no salvage price
	Refill of soap, dispenser, for th 5 rooms[b]	179.50	Price per refill of a hand soap €3.59 www.agrologic.be. Assume 10 refills per year.
	Extra time and 4 visits per day	162.22	Assume time for hand washing (20 seconds extra) and 4 visits per day. Labor cost: €20/hour
Herd specific manure pipes	Purchase of 2 manure pipes	76.00	Assumed price of pipes €200, assume two pipes are bought and there is a 5 years amortisation following linear depreciation with €10 salvage price
Hygiene while handling the cadaver	Use of gloves	20.00	Assume weekly collection of cadavers. Price of the gloves: €10 per box of 100 units www.agrologic.be

Keep domestic animals outside	Purchase of foam to close small holes in the farm	100.00	Assume that keeping pets outside the barn premises incurs no added costs Assume price of the foam purchased to seal small holes (€100)
Vermin control	Contracted company to visit farms	1,500.00	Price of the vermin control by professional company: €1,500/visit (www.agrologic.be)
Water bacteriological characteristics	Taken by vet/company and analysis	178.00	Assume 2 times/year. Cost of bacteriological analysis is €89 (DGZ[c])
Internal biosecurity	Parameters	Costs (€/farm/year)	Source
Attention at farrowing	Spent 30 seconds extra per piglet born	Farm specific (average 150.83)	Assume that 30 seconds are spent per piglet born; labor cost: €20/hour
Causes of piglet mortality	Record the number of dead piglets and the causes of the dead piglets	243.33	Assume 2 minutes per day. Labor cost: €20/hour
Change of needle	Change of needle per litter for the piglets, change of needle per 10 sows	Farm specific (151.79)	Price of needles (€6.31 for a box with 100 needles) from www.agrologic.be. Assume 1 needle is used per group of 11-12 piglets, 1 needle for groups of 10 sows/finishers
Cleaning and disinfection	Cleaning and disinfection of the barns between rotations	1,560.00	Assume 6 hours needed to clean and disinfect the farm premises between rotations 13 times per year. Assume that it was not done before. Labor cost: €20/hour
Creation of a sickbay policy	Formulate the protocol: 2 h labor farmer, 4 times per year	160.00	Assume 2 hours needed to create the sickbay policy; labor cost: €20/hour
Different materials per department	Use of different: 1) handling boards, 2) brooms, 3) spades, 4) bucket, 5) floor scraper, 6) tool box/treatment box. For the five rooms[b]	258.33	Prices of i) handling boards (€25/board), ii) brooms (€25/broom), iii) spades (€45/spade), iv) bucket (€5/bucket), vi) toolbox/treatment box (€30/toolbox) from www.agrologic.be. Assume 3 years linear depreciation and no salvage price
Disinfection of the boots between the different units	Boot washer for the 5 rooms[b]	110.00	Price of the boot washer (€150/unit) www.agrologic.be. Assume 10 years amortisation with linear depreciation and €50 salvage price and costs of disinfectant per year (€60) from www.agrologic.be
	Boot storage rack one per each of the 5 rooms[b]	30.00	Price of the boot storage rack (€100) from www.agrologic.be, assume 10

			years of amortisation and €40 salvage price
Euthanasia of diseased pigs	Euthanasia of severely diseased animals	Farm specific (average 13.18)	Assume 1% of live born piglets need to be euthanized; 1 ml/piglet. And 2% of sows need to be euthanised, with 50 ml/sow per sow of 220 kg. Assume price of bottle of euthanasia product of €45.60/l
Hygienogram	Total bacterial count 40 plates/year	80.00	Assume 4 times/year bacteriological count, at 10 locations, €2/plate
	Sending and analysis, 4 times/year	24.00	Sending and analysis price: €6, 4 times/year (DGZ[c])
Iodine after castration	Use of iodine after castration of the piglets	Farm specific (average 254.61)	Assume using 3 ml per piglet after castration. Price of iodine €10,21/liter (www.agrologic.be)
Isolate sick animals	Bring the smaller and sick animals to euthanasia or to the sick bay	120.00	Assume an increase in management time of 30 minutes per month.
Washing the sows before farrowing	Farm specific (depending on farrowing index and number of sows)	Farm specific (average 185.91)	Price of commercial shampoo based on quaternary ammonium compounds for sows: €75 for a 25-l can. 50 ml used per sow, €0.15 per sow from www.agrologic.be (used by 3 farm), used before farrowing
			Price of a commercial detergent based on chlorhexidine, assume use of 15 ml per sow. A 5-l can costs €56.71 or €0.18 per sow from www.agrologic.be (used by 4 farms)
			Price of a commercial detergent based on chloroxynelol, assume use of 15 ml per sow, a can of 25 l costs €85, €0.05 per sow from www.agrologic.be (implemented by 1 farm)
			Assume 1 hour to wash 50 sows

[a] The truck that collects culled sows or the destruction company should be empty and clean

[b] The five rooms are: farrowing, nursery, finishing, quarantine and sick bay

[c] Animal Health Care Flanders

Table 2. Prices per dose of vaccination (including VAT) obtained from 2 herd veterinarians administered by farmers after visit 2 and number of farms which implemented the advised vaccinations.

	n farms implemented	Price per dose
E. coli[a] and *Clostridium*	1	€ 1.71
H. parasuis[b]	2	€ 1.17
Influenza	3	€ 1.69
M. hyopneumoniae[c]	1	€ 0.71
PCV[d]	4	€ 1.27
PRRSv[e]	3	€ 1.68

[a] *Escherichia coli*

[b] *Haemophilus parasuis*

[c] *Mycoplasma hyopneumoniae*

[d] Porcine Circovirus

[e] Porcine Reproductive and Respiratory Syndrome virus

Table 3. Variables describing the 11 virtual farrow-to-finish pig representative farms for Flanders (Belgium) obtained after performing an average linkage cluster analysis based on the technical and cost allocative efficiency of the FADN-full sample of farrow-to-finish pig farms for the years 2010, 2011, and 2012.

	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6	Farm 7	Farm 8	Farm 9	Farm 10	Farm 11
Finishing phase											
Starting weight piglets (kg)[a]	22.1	23.2	23.0	20.0	22.0	22.0	21.1	20.1	24.7	24.5	23.5
PF_F (€/kg)[b]	0.26	0.26	0.25	0.26	0.26	0.24	0.25	0.26	0.26	0.24	0.27
Finishing pigs' final weight (kg)	111	107	109	111	111	121	111	111	108	114	111
Average number of present finishing pigs	1,239.0	941.1	895.7	1,229.2	1,171.8	1,707.4	1,203.9	1,071.4	339.2	1,020.0	803.5
PY_F (€/kg)[c]	1.20	1.19	1.17	1.19	1.20	1.18	1.21	1.19	1.16	1.18	1.19
MF (%)[d]	2.18	4.06	2.68	1.29	3.52	1.75	6.15	2.66	3.59	2.13	4.53
ADWG (g/day)[e]	709	651	613	665	622	762	609	645	654	561	579

FC (kg/kg)[f]	2.77	2.85	3.08	2.51	2.95	2.78	3.09	2.76	2.68	3.33	3.25
Farrowing phase											
PF_S (€/kg)[g]	0.26	0.27	0.26	0.26	0.26	0.26	0.25	0.26	0.26	0.19	0.26
PF_P (€/kg)[h]	0.39	0.38	0.35	0.37	0.38	0.40	0.38	0.40	0.38	0.39	0.39
Average number of gilts	18	15	10	22	11	17	10	10	9	12	8
Average number of sows	162	146	132	140	150	220	148	143	61	161	118
Average number of piglets	839	755	625	763	693	1,150	695	650	274	510	583
Weaning age (days)	25	24	30	25	26	24	25	22	30	24	27
Litter size[i]	11.97	11.45	10.13	11.82	11.82	10.75	11.62	12.49	9.09	9.77	10.74
Farrowing index[j]	2.40	2.23	2.09	2.21	2.21	2.33	2.31	2.29	2.13	1.96	2.16
Mortality of piglets (%)[k]	10.04	17.61	12.85	6.16	18.26	10.75	11.62	13.94	9.02	15.13	13.53

[a] Weight of the piglets at the beginning of the finishing period

[b] Prices for kg of feed for finishers (€/kg)

[c] Prices for kg of living weight of the finishers (€/kg)

[d] Mortality of the finishers since the beginning of the finisher period till the end of the finishing period (€/kg)

[e] Average daily weight gain of the finishing period (g/day)

[f] Feed conversion of the finishers or feed consumed by the finishers divided by the kg of pork meat produced by the finishers (kg/kg)

[g] Prices for kg of feed for sows and gilts (€/kg)

[h] Prices for kg of feed for piglets (€/kg)

[i] Number of piglets born alive per litter

[j] Number of farrowings per year

[k] Mortality of the piglets which includes the mortality till weaning and the nursery mortality (%)

Table 4. Correlation matrix of the feed prices for finishers (PF_F), sows (PF_S) and piglets (PF_P) and the prices of the finishers (PY_F) and piglets (PY_P) estimated with official monthly data from the Flemish government for feed prices (Department of Agriculture and Fisheries, Flemish Government) and data of a Belgian feed company for the prices of the finishers and piglets (Anonymous, 2010; 2011; 2012) for the years 2010, 2011 and 2012.

	PY_F[a] (€/kg)	PF_F[b] (€/kg)	PF_S[c] (€/kg)	PF_P[d] (€/kg)	PY_P[e] (€/piglet)
PY_F[a] (€/kg)	1.00	0.54	0.53	0.54	0.68
PF_F[b] (€/kg)	0.54	1.00	1.00	1.00	0.00
PF_S[c] (€/kg)	0.53	1.00	1.00	1.00	0.00
PF_P[d] (€/kg)	0.54	1.00	1.00	1.00	0.00
PF_P[e] (€/piglet)	0.68	0.00	0.00	0.00	1.00

[a] Feed prices for finishers

[b] Feed prices for sows

[c] Feed prices for piglets

[d] Prices for finishers

[e] Prices for piglets

Table 5. Summary statistics of the covariates: building year of the oldest building, farmer's years of experience, number of employees, number of sows of the 48 treated farms and 69 control farms.

	Treated		Control	
	n	Mean (SD)	n	Mean (SD)
Building year of oldest building	48	1985.4 (8.0)	69	1985.3 (9.4)
Farmers' years of experience	48	21.8 (8.6)	69	21.6 (9.4)
Number of employees	48	1.9 (0.9)	69	1.7 (0.8)
Number of sows	48	300.9 (178.7)	69	174.6 (135.9)

Table 6. Summary statistics of the average daily weight gain (ADWG), farrowing index (FI), litter size (LS), mortality of the finishers (MF), for the 48 treated farms in visit 2, visit 3 and the 69 control farms in 2011, 2012.

	Treated					Control				
		Visit 2	Visit 3	Difference			2011	2012	Difference	
	n	Mean (SD)	Mean (SD)	Mean (SD)	P-value	n	Mean (SD)	Mean (SD)	Mean (SD)	P-value
ADWG[a]	25[b]	641.17 (85.92)	668.54 (78.86)	27.37 (76.64)	0.09	69	641.81 (63.65)	637.85 (66.53)	-3.96 (58.24)	0.57
FI[c]	36[d]	2.39 (0.07)	2.38 (0.08)	-0.01 (0.06)	0.26	69	2.18 (0.24)	2.18 (0.26)	0.00 (0.18)	0.90
LS[e]	36[f]	13.05 (1.15)	13.41 (1.28)	0.35 (0.50)	<0.01	69	11.71 (1.31)	11.78 (1.31)	0.07 (0.66)	0.40
MF[g]	32[h]	3.46 (2.40)	2.59 (1.74)	-0.87 (1.79)	0.01	69	2.45 (1.40)	2.47 (1.38)	0.02 (1.13)	0.88

[a] Average daily weight gain (g/day)
[b] In total, 23 farms had missing values for average daily weight gain (g/day) in the first, third or both visits
[c] Farrowing index (number of farrowings/year)
[d] For the farrowing index, there were 12 missing values in the first, third or both visits
[e] Litter size (number of piglets born alive/year)
[f] For the litter size there were 12 missing values in the first, third or both visits
[g] Mortality of the finishers (%)
[h] For the mortality of the finishers (%) there were 16 missing values in the first, third or both visits

Table 7. Summary statistics of the technical parameters' difference in differences (DID) between the third and second visit and between treated and control farms estimated with genetic propensity score matching.

Difference in differences	Mean (Abadie-Imbens SE) (%)	P-value
Average Daily Weight Gain (g/day)	5.9 (3.4)	0.09
Farrowing Index (number of farrowings/year)	1.9 (2.1)	0.37
Litter Size (number of piglets born alive/year)	0.9 (1.1)	0.40
Mortality of the Finishers (%)	-1.1 (0.5)	0.03

Table 8. P-value of the two-sample t-test distribution of the covariates on the 4 propensity score analyses conducted for average daily weight gain (ADWG), farrowing index (FI), litter size (LS), and mortality of the finishers (MF).

	ADWG[a]		FI[b]		LS[c]		MF[d]	
covariates	Before match.	After match.	Before match.	After match.	Before match.	After match.	Before match.	After match.
Building year of the oldest building	0.80	0.13	0.85	0.64	0.86	0.64	0.59	0.66
Farmers' years of experience	0.68	0.69	0.62	0.48	0.62	0.48	0.95	0.29
Number of employees	0.52	0.41	0.58	0.63	0.57	0.63	0.42	0.41
Number of sows	<0.01	0.08	<0.01	0.09	<0.01	0.09	<0.01	0.23

[a] Average daily weight gain (g/day)

[b] Farrowing index (number of farrowings/year)

[c] Litter size (number of born alive piglets/sow/year)

[d] Mortality of the finishers (%)

Table 9. Difference of the enterprise profit after-before the MI in €/sow/year between the simulation, which did not account for volatility of the prices (No volatility) and the simulation which accounted for volatility (Volatility) simulated for 1,000 Markov Chain Monte Carlo iterations with an stochastic production input-output model for 11 Flemish virtual representative farrow-to-finish pig farms.

	ΔEnterprise profit No volatility $_{\text{after-before}}$ (€/sow/year)		ΔEnterprise profit Volatility $_{\text{after-before}}$ (€/sow/year)	
	Mean (SD)	95% CI	Mean (SD)	95% CI
Farm 1	153.44 (56.99)	38.00, 262.00	58.99 (59.12)	-63.77, 179.58
Farm 2	114.94 (46.83)	15.19, 200.58	39.94 (49.00)	-57.62, 137.23
Farm 3	62.38 (51.35)	-44.82, 164.41	42.54 (59.12)	-64.38, 148.76
Farm 4	98.21 (69.29)	-43.00, 237.00	76.53 (71.21)	-65.51, 229.69
Farm 5	74.91 (56.56)	-43.20, 187.26	45.90 (60.11)	-87.66, 161.73
Farm 6	108.23 (63.01)	-18.00, 233.00	69.06 (66.72)	-68.97, 200.60
Farm 7	96.18 (55.72)	-21.57, 201.94	41.06 (59.83)	-95.36, 156.59
Farm 8	217.53 (52.68)	108.06, 312.36	43.09 (58.09)	-95.97, 149.78
Farm 9	55.61 (42.78)	-38.06, 133.38	16.17 (46.61)	-79.01, 95.94
Farm 10	67.22 (40.57)	-23.80, 134.98	17.89 (44.14)	-89.97, 92.06
Farm 11	136.47 (45.97)	38.77, 217.30	21.77 (50.60)	-102.23, 113.80
Mean	107.74 (52.89)	-2.95, 207.66	42.99 (56.78)	-79.13, 151.43

Table 10. Difference of the enterprise profit after-before the MI when price volatility was modelled in simulated for 1,000 Markov Chain Monte Carlo iterations with an stochastic production input-output production economic model for 11 Flemish virtual representative farrow-to-finish pig farms.

	ΔEnterprise profit after-before (€/sow/year)		ΔEnterprise profit after-before (€/APFP[a]/year)		ΔEnterprise profit after-before (€/FP[b]/year)	
	Mean (SD)	95% CI	Mean (SD)	95% CI	Mean (SD)	95% CI
Farm 1	58.99 (59.12)	-63.77, 179.58	7.86 (7.79)	-8.29, 23.73	3.00 (2.72)	-2.58, 8.47
Farm 2	39.94 (49.00)	-57.62, 137.23	6.30 (7.64)	-8.83, 21.57	2.68 (2.79)	-2.85, 8.46
Farm 3	42.54 (59.12)	-64.38, 148.76	6.34 (8.03)	-9.46, 22.03	2.91 (3.14)	-3.35, 9.08
Farm 4	76.53 (71.21)	-65.51, 229.69	8.78 (8.13)	-7.45, 26.37	3.78 (3.20)	-2.77, 10.59
Farm 5	45.90 (60.11)	-87.66, 161.73	5.98 (7.73)	-11.01, 20.99	2.71 (3.06)	-4.03, 8.58
Farm 6	69.06 (66.72)	-68.97, 200.60	9.15 (8.72)	-8.17, 26.56	3.50 (3.16)	-3.04, 9.89
Farm 7	41.06 (59.83)	-95.36, 156.59	5.17 (7.43)	-11.75, 19.59	2.43 (3.01)	-4.56, 8.28
Farm 8	43.09 (58.09)	-95.97, 149.78	5.87 (7.82)	-12.53, 19.59	2.59 (3.02)	-4.88, 8.03

Farm 9	16.17 (46.61)	-79.01, 95.94	2.97 (8.39)	-14.14, 17.38	2.15 (2.33)	-4.40, 7.41
Farm 10	17.89 (44.14)	-89.97, 92.06	2.95 (7.02)	-14.07, 14.73	1.78 (3.22)	-6.38, 7.29
Farm 11	21.77 (50.60)	-102.23, 113.80	3.24 (7.43)	-14.96, 16.75	1.89 (3.10)	-5.77, 7.39
Mean	42.99 (56.78)	-79.13, 151.43	5.87 (7.83)	-11.02, 20.93	2.67 (2.98)	-4.06, 8.50

[a] average present finisher pig

[b] finisher pig