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Antibiotics use versus profitability on sow farms in the Netherlands

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A B S T R A C T

In 2009, the Dutch government provided policy objectives (i.e., targets) for a reduction in veterinary antibiotics use of −20 % in 2011, −50 % in 2013 and −70 % in 2015 relative to the use in 2009. The relationship between antibiotics use and performance of Dutch sow farms during this policy reform was analysed using the Farm Accountancy Data Network database comprising cross-sectional farm data from 2004 to 2016. The results show that there is a significant downward trend in antibiotics use of 57 %. Panel data analysis (n = 74 sow farms) revealed that the reduction in antibiotic use did not lead to negative effects on technical or economic farm results. A follow-up survey was conducted on measures taken to improve animal health, which made the reduction in antibiotic use feasible. Of the 79 sow farmers approached, 55 participated in this survey. Sow farmers used a variety of relatively easy and affordable measures, such as more attention to hygiene, use of pain killers and anti-inflammatory agents, or applied more preventive vaccinations. Multivariable linear regression models showed that the intention, perceived risk and uncertainty, and perceived capability (to keep or get the use of antibiotics under the target value) were the most important predictors for antibiotics use from 2014 to 2016. Sow farmers who used more antibiotics were more concerned that low antibiotics use compromises their farm results, perceived more risk and uncertainty, and thought to a lesser extent that they have enough knowledge and time. These results indicate that providing these farmers with knowledge and information on management practices to reduce the use of antibiotics may be helpful. Thereby, it would be useful to focus on continuous involvement of the veterinarian and possibly the feed supplier, preferably by means of individual advice, as the results showed that individual advice was the preferred way to gather knowledge for the interviewed sow farmers and the veterinarian appeared to be the most important source of information to the interviewed sow farmers, followed by the feed supplier. In summary, the study shows that decrease in antibiotics use can be quite successful without compromising on the economic or technical performance, and moreover taking into account farmers' attitudes, perceptions and preferences can be helpful to get a better understanding of farmers' decision making and is useful for the design of tailor-made interventions.

1. Introduction

Antimicrobial resistance is one of the most serious public health crises today. Governments, leading medical and public health organizations around the world agree with that. Therefore, worldwide initiatives are taken and action plans are developed to reduce antimicrobial resistance both at national and international level (WHO, 2016). In many countries, and also in the Netherlands, governments steer towards a reduction in veterinary antibiotic use as an important pathway to limit (the further) development of antimicrobial resistance (Laxminarayan and Brown, 2001). Antibiotic resistance can reduce the effectiveness of human medicine. As a result, a reduction of antibiotic use in livestock farming will limit the selection for resistant bacteria, which will reduce the risk of their transmission to humans (Bondt et al., 2016).

The Dutch authorities requested the Dutch Veterinary Association to develop an antibiotic policy in 1990 (Bondt et al., 2016). Subsequently in 2008, the Dutch government together with the Dutch Veterinary Association and livestock sectors took the initiative to decrease antibiotics use in the livestock sector as laid down in a memoranda of understanding (Bondt and Kortstee, 2016; Bondt et al., 2016). In 2009, the government provided objectives (i.e., targets) for a reduction in veterinary antibiotics use: −20 % in 2011, −50 % in 2013 and −70 % in 2015 relative to the use in 2009 (Bondt et al., 2016). Moreover, European Union forbade the use of so-called AGPs (Antibiotic Growth Promoters) in 2006 (European Commission, 2005).

Bondt et al. (2016) noted that farmers may have an inclination to change their antibiotics due to concerns over health impacts of

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antibiotics use on themselves or people close to the farm. However, since reducing antibiotic use on farms involved in most cases implementing measures to enhance animal health and changing animal health management, farmers are concerned of associated costs (Coyne et al., 2014) and whether this does have a negative implication for the economic performance of the farm (Speksnijder et al., 2015; Visschers et al., 2016).

Multiple studies report on the factors that are associated with antibiotics use. Most academic publications suggest that there does not exist an effect of decreased antibiotics use on economic performance. For instance, the relation between antibiotics and profitability was tested prior and after the AGP ban. The AGP ban did not affect the productivity or the profitability of the different farms (Emborg et al., 2001; Aarestrup et al., 2010). It should be noted, however, that in the Netherlands, the reduction in the use of growth promoters in the years before 2006 was almost entirely offset by an increase in therapeutic antibiotic use. Furthermore, nursery pig farms had serious problems and showed a significant association between antibiotic use and productivity (McDowell et al., 2008). Other authors state that risk and uncertainty play a role as risk-averse farmers may tend to use more antibiotics (Ge et al., 2014). Nevertheless, antibiotics can be used in reaction to mask poor management or animal health (Ge et al., 2014). In accordance with this, recent intervention studies showed that preventive measures can decrease the need for antimicrobials and create economic net benefits. A relevant preventive measure, for a pig finishing farm, is the purchase of piglets with a high health status from a known producer (Kruse et al., 2018, 2019). Farmers may perceive antibiotics or antimicrobials as a less costly solution and therefore more cost-effective than vaccinations or other preventive measures. Other research point towards a lack of knowledge of farmers on preventive measures (Moreno, 2014; Speksnijder et al., 2015a). Even some pig vets feared that a ban on antimicrobials may have negative consequences for the productivity of livestock production (Coyne et al., 2014). Yet, most of these studies primarily focussed on productivity rather than economic performance, or did not link behaviour with economic performance. However, to help farmers to change their daily practise, insight is needed on their willingness and motivation to change, on their capability and ability to change, on factors that influence this capability and ability, e.g. knowledge and education, and on the opportunity to change, e.g. possible constraints regarding time, money or a suitable housing system (Ölander and Thøgersen, 1995; Michie et al., 2011). Background of this is that uptake and upscaling of promising interventions often is disappointing. A reason for this may be that it is often assumed that farmers and other agents are rational, self-interested economic agents. However, new insights have made increasingly clear that psychological and sociological elements should also be taken into account, with consideration of intrinsic motivations, moral convictions, social preferences, reciprocity and the impact of peer groups (Edwards-Jones, 2006; Herzfeld and Jongeneel, 2012; Garforth, 2014).

The objective of this study was twofold, namely to test the association between antibiotics use and farm performance of sow farms in the Netherlands by means of panel data analysis, and to gain insight in behavioural factors, such as intentions, attitudes, beliefs and perceptions, that explain the behaviour response to keep or get the use of antibiotics under the target value by means of a complementing survey among farmers in the panel. Sows farms were chosen due to the larger antibiotics use relative to fattening pig farms. The time period of interest was from 2004 to 2016, which captured the period with structural reforms in antibiotic use of 2011, 2013 and 2015. The use of antibiotics decreased approximately with 50 % from 2009 to 2014 (Bondt and Kortstee, 2016) and thus provided the opportunity to estimate the impact and behavioural responses of a sharp decline in antibiotic use.

2. Method

2.1. Data collection

Multiple steps were needed to estimate the relation between antibiotics use (MARAN, 2002-2019; MARAN, 2002) and the farm performance (Agrimatie, 2019). Analysis was based on the Farm Accountancy Data Network (FADN) panel dataset of Wageningen Economic Research. The FADN dataset contained repeated measurements of technical as well as economic variables per year for (among others) Dutch sow farms (n = 79). It was a rotating (unbalanced) panel to reduce attrition. The availability of repeated observations on the same units made it possible to specify and estimate more complicated and more realistic models than a single cross-section or a single time series would do. Since the observations were repeated on the same unit, it was no longer appropriate to assume that different observations are independent (Hsiao, 1985). In addition, a follow-up survey was carried out among FADN sow farmers to gather additional data on behavioural factors such as intentions, attitudes, beliefs and perceptions (see Section 2.4) that may lead to a lower number of daily doses of antibiotics per animal year (NDD). Calculating NDD requires detailed information about the amount of individual active substances used per animal species (Bondt et al., 2013). The survey data were collected by telephone or by visiting the sow farmer, depending on the preference of the farmer.

2.2. Data processing and variable selection

A selection of relevant FADN variables was made based on reviewing literature (Emborg et al., 2001; Argiles and Slof, 2003; Van der Fels-Klerx et al., 2011). Fig. 1 depicts the conceptual model. The antibiotics use is expressed as NDD (number of daily doses per animal year). It is the number of daily doses of all the antibiotics that an animal (on average) receives per year. The independent variables, apart from antibiotics use, were entered into the models in order to account for the (time-varying) variation caused by these variables. This enabled us to see the statistical association between antibiotics use and performance, conditional on the fact that all other factors are constant.

The five dependent performance variables include farmer income, productivity measures (delivered piglets per sow), total revenue, animal health costs and total costs. These had a (financial) hierarchical structure as animal health costs are part of the total costs, delivered animals are part of the total revenue, and total costs and total revenue are part of the farmer income. This allowed us to view the effect of antibiotics use at different levels of farm recordings. The independent variables can have an association with all the dependent variables in the conceptual model, apart from the independent variable of price. The age of the farmer may have affected the performance of a farm (Argiles and Slof, 2003). Additionally, the number of sows present on the farm may have affected the performance as it allows for scale efficiencies. Furthermore, the modernity of the farm may have influenced the performance of the farm as differences in the level of technology implementation may explain performance. Modernity was operationalized as the percentage of the current balance value of the buildings divided by the new value of the buildings. The model included labour per sow as this controls for differences in performance due to labour intensity. The model also included the feed-related variables piglet feed per piglet per year, sow feed per sow per year, sow feed price and piglet feed price. The feed costs had a significant share of the total costs (Hoste, 2017), so they would have had a considerable influence on the (financial) farm performance. The financial (performance) variables (i.e. income, costs and revenues) are divided by the average number of sows present on the farm to increase interpretability.

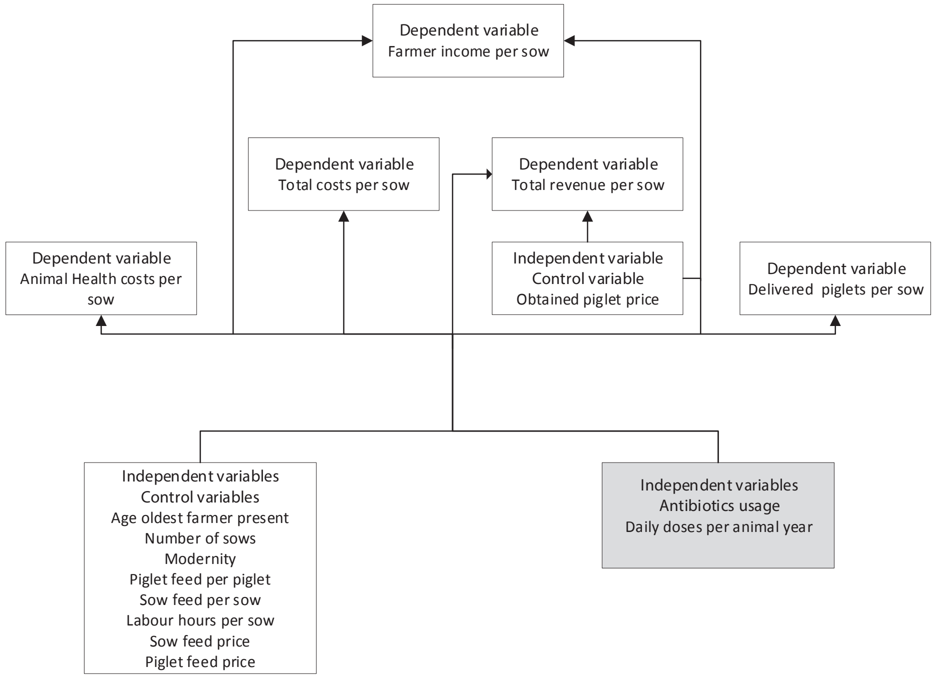

Fig. 1. The conceptual model for sow farms that visualizes the associations between the dependent variables (antibiotic use) and the independent variables.

2.3. Panel data analysis

The first step was to analyse the trend of antibiotics use in the Netherlands in the past years. NDD was approximated with a linear regression function to test for structural changes before and after 2008. Subsequently, both fixed effects and random effects models were estimated. In essence, functions of different variables measuring performance were estimated. We were able to examine whether the antibiotics use affects any of the variables indicating farm performance. The models were defined as follows (Verbeek, 2012):

$$y_{it} = \beta_0 + x_{it}^{'}\beta + \alpha_i + \varepsilon_{it}\ \varepsilon_{it}\ \sim IID(0,\ \sigma_\varepsilon^2)$$

where y_{it} is the dependent economic variable of farm i at time t, β_0 is the common intercept term for all subjects over all observations, $x_{it}^{'}$ is the vector of independent variables (including antibiotics use) of farm i at time t, β is the vector of coefficients describing the relationship between $x_{it}^{'}$ and y_{it} and ε_{it} is the observation specific residual term. These residual terms are assumed to follow a normal distribution with a mean of 0 and a constant standard deviation of σ_ε^2. In the case of a fixed effect model, α_i is a subject-specific intercept. In the case of a random effects model, it is assumed that α_i is a subject-specific residual that follows a (usually normal) distribution with a standard deviation σ_α^2. The random effects model assumes that there is no correlation between the residuals (both α_i and ε_{it}) and all independent variables in the model. The relation between antibiotics use and the farmer income, given all other covariates, was explored by looking at the significance of the coefficient of the antibiotics use. This study used a significance level of 0.05. In addition, the standard errors of the coefficients are clustered around the farm ID, making them robust for heteroscedasticity and autocorrelation caused by repeated measures on the same farm (the firm effect) and reducing the probability of a type II error (Petersen, 2009). Therefore, clustered standard errors were used to adjust the standard errors for deviations from an independent and identically distribution $IID(0,\ \sigma_\varepsilon^2)$ due to the firm effect (Abadie et al., 2017). The random effects model was preferred over the fixed effects model as it was assumed that these farms are drawn from a larger distribution of Dutch sow farms. However, it may not always be possible due to a correlation between the subject-specific residual (α_i) and any of the independent variables in the model (causing endogeneity and biased estimates). In these cases, this paper used a fixed effects specification. The Hausman test can be used to determine whether to use a random or a fixed effects model (Verbeek, 2012). The null hypothesis stated that the coefficient estimates are consistent for both the fixed and the random effects model, although the random effects model is more efficient in its estimates. However, models with clustered standard errors of coefficients cannot be compared in the Hausman test. As a result, the Hausman test was done without clustered standard errors. The Sargan-Hansen overidentification test (implemented in Stata as XTOVERID (Schaffer and Stillman, 2016)) allows clustered standard errors. Therefore, the Sargan-Hanssen test is used in addition to the Hausman test.

The analysis showed that the data did not seem to adhere to the asymptotic properties of the Hausman test. This may be attributed to the fact that there is still autocorrelation between residuals, which is possible due to the Hausman test not supporting models with clustered standard errors. In the presented models, this autocorrelation was corrected for in the clustered standard errors, as indicated above. Wooldridge (2001) states that “the resulting test could have an asymptotic size larger or smaller than the nominal size.” In this case, the sigmamore option of the Hausman test was needed. This ensures that the Hausman test adheres to the needed asymptotic properties. The Sargan-Hansen overidentification test was chosen in case the results of the tests were in disagreement as the sigmamore is a somewhat ad hoc solution. These models were built and tested using Stata 14 (StataCorp, 2015).

2.4. Behavioural factors attributing to antibiotics use

In order to explore the behavioural factors that explain the decision to decrease the antibiotics use, constructs related to the Theory of Planned Behaviour (TPB) are used (Ajzen, 1991). The theory states that the intention of an individual to perform a certain behaviour – for example to use less antibiotics for sows – is influenced by his or her attitude towards the behaviour, the opinion of important others (social norm) about the behaviour and the individual’s perception of the control he or she has over the behaviour (perceived behavioural control) (Ajzen, 1991). Attitude can be explained by behavioural beliefs and evaluation of the outcome. Behavioural beliefs are the believed consequences of the proposed action (e.g. attempting to limit antibiotics use will result into lower economic performance), and the evaluation of outcome is the value that individuals place on an outcome social norms can be linked to the normative beliefs and the motivation to comply. Normative beliefs can be defined as "the likelihood that important referent individuals or groups approve or disapprove performing a given behaviour", and motivation to comply can be referred to as the tendency to follow a normative belief, dependent on the person who represents the belief (i.e. what is the influence of the veterinarian on your decision to limit antibiotics use?). Perceived behavioural control (PBC) can be defined as the confidence an individual has in his or her skills to perform the behaviour. It can be divided in PBC-capability and PBC-controllability, and is linked to control beliefs, which can be defined as the believed "presence or absence of requisite resources and opportunities" (Ajzen, 1991).

In addition to the TPB-related constructs, constructs related to perceived risk and uncertainty and relative risk perception (perception of the environment) are included. This is important because farmers who perceive less risks are probably less willing to adopt preventive measures (Kunreuther et al., 2001; Ogurtsov et al., 2008). Perceived uncertainty can be described as the perceived probability to succeed in the behaviour (i.e. I am uncertain whether I can limit my antibiotics use).

The concept variables (constructs) are created by combining separate items (questions) of the FADN follow-up survey as these concept variables are hard to measure directly. The separate items were mostly measured on a 7-point scale where 1 was the most negative answer (e.g. totally disagree, very unlikely), and 7 the most positive answer (e.g. totally agree, very likely). The negatively worded items are inversely recoded. Next, the internal consistency of the separate items to-be-combined into one concept variable (construct) are tested by Cronbach's alpha (as explained by Tavakol and Dennick (2011)). Tavakol and Dennick (2011) state that these values should range from 0.70 to 0.95. After the result is deemed satisfactory, the mean is taken for all the measurements of these items to obtain a value for a single conceptual construct.

Regression analysis is applied to explore the linkage between the concepts described in the framework. The skewed NDD data is log transformed to conform to normality. Next, the association between the average yearly use and the information gathered from the survey data are analysed. In the regression analyses intention, attitude, positive and negative behavioural beliefs, evaluation of outcome, social norm, normative beliefs, motivation to comply, perceived behaviour control, control beliefs and perceived risk and uncertainty are used as predictors. In the multivariable regression analyses, two constructs are not included in the same model if the Pearson's correlation coefficient between them > 0.50. If variables were not normally distributed, the variables were divided into tertiles, with scores ranging from 1 to 3.

3. Results

3.1. Descriptive and trend analysis

The farm dataset consisted of maximally 620 and minimally 371 observations per variable. The mean number of years a farm in the panel was approximately 6 years (Table 1). Substantial heterogeneity was observed between farms as well as within farms (in time).

Fig. 2 depicts the trend and the spread of the number of daily doses of antibiotics per animal per year (NDD). Trends were insignificant up to 2008 (0.97 NDD, $p = 0.36$, $R^2_{adj} = 0.01$), while there was a significant negative coefficient in the linear regression model after 2008 (-2.44 NDD, $p < 0.01$, $R^2_{adj} = 0.15$). Also the Dutch Veterinary medicine authority reported a 57 % decline of NDD in pig production from 2009 to 2016 (Stichting Diergeneesmiddelen Autoriteit, 2018).

3.2. Panel data analysis

All five regression models included fixed effects specifications as indicated by the Sargan-Hansen overidentification test and the Hausman test (Table 2). Moreover, the within R^2 tended to be higher than the between R^2 or overall R^2 with fixed effects models. This difference was caused by the focus of the fixed effects model on explaining within-subject variation rather than between or overall variation (Wooldridge, 2001).

The coefficients of NDD in the delivered piglets per sow, animal health costs per sow, the total costs per sow, total revenue per sow and farmer income per sow models were all not significant at a significance level of 0.10. Overall, no significant performance-increasing association of NDD (decreasing in costs or increasing in revenues, production or income) were found.

The Wald or F-tests of all the models rejected the null hypothesis (with a significant level of 0.05) of all coefficients in the model jointly having no additional explanatory power compared to an intercept-only model. As expected, input and output confounding variables had a large influence on overall costs, revenues and income (i.e., piglet feed per piglet, piglet price, sow feed per sow, sow feed price and labour hour per sow). Furthermore, the association between modernity of the farm and farm performance was statistically significant with respect to delivered piglets per sow and animal health costs (at a significance level of 0.01). More modern buildings were associated with less animal health costs.

Other confounding variables were not or hardly significant in any model. These variables included for example the age of the oldest farmer present and number of sows. Re-estimating models with these insignificant variables hardly affected coefficient estimates for NDD.

3.3. Behavioural factors attributing to antibiotics use change

Of the 79 sow farmers approached, 55 participated in the survey. Table 3 shows a summary of the measures interviewed sow farmers took to improve the health of their animals or the health status of their farms. Measures focused mainly on animal health management, such as improving biosecurity, use of anti-inflammatory agents or preventive vaccinations. The majority of the famers indicated in the interviews that they implemented the measures less than nine years ago (the moment that the Dutch government provided objectives for a reduction in veterinary antibiotics use: 20 % in 2011, 50 % in 2013 and 70 % in 2015 relative to the use in 2009). Once implemented, most farmers continued taking these measures.

The veterinarian appeared to be the most important source of information to the interviewed sow farmers, followed by the feed supplier (mean score 6.4 and 5.4 respectively). The interviewed sow farmers also complied the most to the veterinarian, followed by the feed supplier and the customer (mean score and 6.3, 5.0 and 5.0 respectively). Individual advice is the preferred way to obtain information (mean score 6.2), followed by study groups (5.3), internet (5.1) and research reports (5.1).

Multivariable regression analyses to find the best predictors of antibiotics use (expressed as the logarithm of the average number of daily doses per animal year from 2014 to 2016) revealed two alternative models (Table 4). In model 1 the intention, to keep or get the antibiotics use under the target value, and perceived risk and uncertainty were the most important predictors of antibiotics use ($R^2_{adj} = 0.39$, $n = 35$). In the alternative model 2, the intention and the perceived capability to keep or get the antibiotics use under the target value seemed to be the most important predictors ($R^2_{adj} = 0.39$, $n = 32$).

The univariate regression analyses indicated that sow farmers who use less antibiotics compared to sow farmers that use more antibiotics (Table 5):

- Had a higher intention to get or keep the use of antibiotics under the

Table 1
Descriptive statistics Dutch sow farms for time period 2004–2016.

Variable	Mean	Std. Dev.	Observations (N)	Farms (n)
Independent variable				
Number of daily doses of antibiotics (NDD per animal year)	17.2	15.94	371	75
Dependent variables				
Delivered piglets per sow (per year)	25.7	3.6	605	103
Animal health costs per sow (in euro per year)	71.8	33.6	604	103
Total costs per sow (in euro per year)	1251.2	420.7	605	103
Total revenue per sow (in euro per year)	1326.1	492.4	605	103
Farmer income per sow (in euro per year)	73.9	230.5	605	103
Confounding variables				
Number of sows	577.6	460.5	605	103
Modernity buildings (% of new value)	41.0	16.0	620	106
Age of oldest farmer present (in years)	49.9	8.8	618	105
Labour hours per sow (in hours)	13.3	11.1	605	103
Piglet feed per piglet (in kg)	28.6	7.9	603	103
Sow feed per sow (in kg)	1478.8	686.1	603	103
Piglets feed price per 100 kg (in euro)	36.1	11.7	603	103
Sows feed price per 100 kg (in euro)	23.5	5.3	603	103
Obtained piglet price (in euro per piglet)	41.6	7.0	605	103

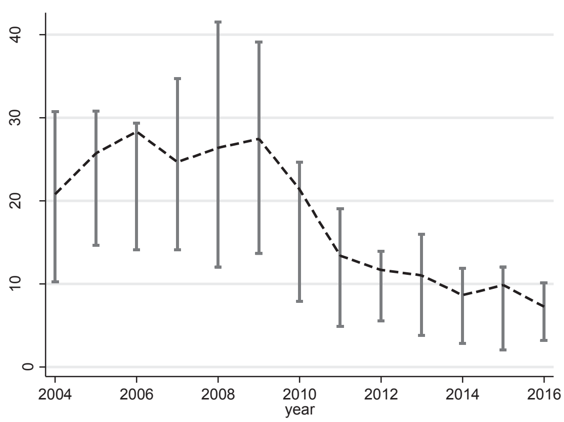

Fig. 2. Mean and 25-75 % percentile interval of the number of daily doses of antibiotics (NDD) per animal year per Dutch farm from 2004-2016.

target value and are more positive about it;

- Thought to a lesser extent that farm results will get worse if they reduce the use of antibiotics (separate item of negative behavioural beliefs);
- Thought that less use of antibiotics increases work pleasure and is good for animal health, animal welfare and human health (separate items of positive behavioural beliefs);
- Thought to a higher extent that colleague-pig farmers, customers, the government, the partner and the neighbour expect them to reduce the use of antibiotics (separate items of normative beliefs);
- Perceived to have enough knowledge and time to keep or get antibiotics use under the target value (separate items of perceived behavioural control – capability);
- Perceived less risk and uncertainty.

4. Discussion and conclusions

In general, the adverse effect of antibiotics use of Dutch farms on different indicators of economic performance during 2004 until 2016 was limited. Given the hierarchical structure of the dependent variables used in this study, the effect seems to disappear when economic performance indicators are at a higher aggregated level (from animal health costs to total costs). This may have occurred due to the increased share of other volatile factors explaining the variable at each added hierarchical step and the fact that the effect of antibiotics use may not be larger than the added variation or random error at each added step.

The FADN dataset contained both technical and financial variables. However, data on the health status in general or more specific the number of infected animals is not registered. A farmer may, for instance, use more antibiotics to prevent the spread of animal disease on the farm after introduction. In that instance, it may be economically viable to use more antibiotics. Nevertheless, widespread infections may be more prevalent in the cases of poor animal management. An increase in antibiotics use may be used to compensate for poor animal management (Ge et al., 2014). Therefore, by measuring the effect of antibiotics use, the models may have partly measured the effect of poor animal health management on farm performance. Even more, it may have been the case that, in the later years of the sample, farmers became increasingly proficient in managing livestock with less antibiotics use. If this proficiency of the farmers increased, it may explain the limited influence of antibiotics use on farm performance in our models.

By analysing the entire sample, it was implicitly assumed that the effect of antibiotics use would be the same across this sample. However, it may be the case that the effect of antibiotics use is not the same across subsamples. The Dutch government took the initiative to decrease antibiotics use in the Dutch livestock sector in 2008 (Bondt and Kortstee, 2016). This disruption may have changed the underlying data generating process. Therefore, the sample was divided into subsamples of 2004–2008 and 2009 − 2016. The effect of antibiotics use is different in the case of the total costs per sow in 2004–2008 (significant positive coefficient), while the coefficient of NDD in animal health costs per sow remains significant, but the positive estimator is lower. A possible explanation for this non-robustness of the total cost model may be that after 2009 antibiotics were only used when it was necessary, while it was more freely (inefficiently) used before 2009, adding to the total costs. Our (limited amount of) survey data seem to confirm this. The interviewed farmers used a variety of relatively easy and affordable measures, such as more attention to hygiene, use of pain killers and anti-inflammatory agents or applied more preventive vaccinations to improve animal health and make the reduction in antibiotic use feasible. The majority of the interviewed famers implemented these measures less than nine years ago. From that moment the Dutch government provided clear objectives for a reduction in veterinary antibiotics use: −20 % in 2011, −50 % in 2013 and −70 % in 2015 relative to the use in 2009. Apparently, this clear policy was helpful to stimulate farmers to start taking measures.

The representability of the FADN dataset could be limited as the data was provided on a voluntary basis. This could have led to self-

Table 2
Regression models for Dutch sow farms, estimating the relation between a performance indicator and NDD while controlling for other significant factors for time period 2004-2016.

	Delivered piglets per sow	Animal health costs per sow	Total costs per sow	Total revenue per sow	Farmer income per sow
NDD (per animal year)	−0.0088 (0.343)	0.21 (0.288)	0.40 (0.543)	0.93 (0.903)	−0.43 (0.307)
Number of sows		0.046 (0.024)			
Modernity buildings (% of new value)	−0.13 (< 0.001)	−1.02 (0.001)			
Age of oldest farmer present (in years)					
Labour hours per year per sow (in hours)	0.068 (< 0.001)	0.35 (0.014)	9.61 (< 0.001)	11.73 (< 0.001)	2.55 (0.014)
Piglet feed per piglet (in kg)	−0.050 (0.055)	1.19 (0.006)	10.11 (0.001)		−11.31 (< 0.001)
Sow feed per sow (in kg)	−0.0019 (0.004)				
Piglet feed price per 100 kg					
Sow feed price per 100 kg	0.13 (0.001)		32.72 (< 0.001)	8.08 (0.011)	−25.36 (< 0.001)
Obtained piglet price (in euro)				24.45 (< 0.001)	23.11 (< 0.001)
Constant	31.51 (< 0.001)	48.23 (0.045)	40.62 (0.059)	−36.85 (0.749)	24.66 (0.845)
N	365	365	365	365	365
Number of farms	74	74	74	74	74
P-value Hausman	< 0.001 (1)	< 0.001 (1)	< 0.001 (1)	< 0.001 (1)	< 0.001 (1)
P-value Sargan-Hansen test	< 0.001	< 0.001	0.024	0.002	< 0.001
Model	FE	FE	FE	FE	FE
R2 within	0.313	0.224	0.555	0.541	0.584
R2 between	0.008	0.065	0.397	0.366	0.059
R2 overall	0.065	0.069	0.398	0.318	0.276
P-value Wald/F-test	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

The (clustered) standard errors and P-values are between brackets. The table also includes the number of observations and number of subjects used per model, together with the Hausman test outcome, the outcome of the Sargan-Hansen overidentification test, the chosen model, the within R^2, the between R^2 and the overall R^2. The within R^2 gives the share of within-farm variation that is explained by the model. The between R^2 gives the share of variation between farms that is explained by the model. FE= fixed effects model, RE = random effects model. (1) Means it used the sigmamore option.

Table 3
Measures taken by 40 % or more of the interviewed Dutch sow farmers (n = 55) for time period 2004-2016 to minimise the impact on technical and performance when reducing antibiotic use (% of farmers).

	Measure taken or not and, if yes, when				
Measure	Yes	Yes, > 9 years ago	Yes, 6 − 9 years ago	Yes, 3 − 6 years ago	Yes, < 3 years ago
Avoid routine use of antibiotics	81.8	20.0	12.7	41.8	7.3
More preventive vaccinations	81.5	9.3	11.1	38.9	22.2
Use pain killers and anti-inflammatory agents	76.4	12.7	14.6	36.4	12.7
More attention to pest control (flies, rats, mice)	74.5	34.6	14.6	12.7	12.7
Improve hygiene	67.3	38.2	7.3	14.6	7.3
Shift to individual medicine treatments	65.4	21.8	10.9	20.0	12.7
Improve feed quality	63.0	18.5	7.4	20.4	16.7
Improve climate control	60.0	21.8	5.5	18.2	14.6
More animal health checks	59.3	27.8	3.7	24.1	3.7
Restrict origin of breeding sows	56.4	29.1	9.1	10.9	7.3
Buy healthier/ stronger sows	40.0	18.2	5.5	9.1	7.3

Table 4
Predictors of antibiotics use (logarithm of average number of daily doses per animal year from 2014-2016 (NDD)) based on multivariable linear regression analyses for Dutch sow farms.

Driver of behaviour	Estimate	Standard error	t	95 % Confidence interval	n	R^2_{adj}
Model 1						
Intention[a]	−1.0	0.3	−3.4***	−1.6 to −0.4	35	0.39
Perceived risk and uncertainty[a]	0.4	0.2	2.1**	0.0–0.7		
Model 2						
Intention[a]	−0.9	0.3	−2.7**	−1.6 to −0.2	32	0.39
PBC - capability	−0.3	0.2	−2.0*	−0.6– < 0		

* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.
[a] Transformation into 3 tertiles because construct was not a normal distribution.

selection bias, in which well-performing farms would report their data, while less performing farms would not. This study has compared the antibiotics use in our sample to the antibiotics use of the total population of Dutch sow farms as provided by Stichting Diergeneesmiddelen Autoriteit (2018). Our results indicate that the mean NDD of sows was 27.48 in 2009, while it was 7.25 in 2016 (−73.6 %). Stichting Diergeneesmiddelen Autoriteit (2018) reported a decrease in antibiotics use in pig production of 57 %. In the case of pig production, this includes both sow farms and fattening pig farms. The decreases in antibiotics use are larger in our sample than in the general population. It

Table 5
Univariate regression models estimating the relationship between Dutch pig farmers' attitudes, intention and perceptions and the logarithmic number of NDD (Number of Daily Doses per animal year) from 2014-2016 (CB = Cronbachs Alpha).

Driver of behaviour	CB	Mean (sd)	B	Standard error	t	95 % Confidence interval	n	R^2_{adj}
Intention	0.73	6.1 (1.2)	−0.3	0.1	−2.3*	−0.6 to −0.04	35	0.11
Intention[a]	[a]	[a]	−1.2	0.3	−4.2***	−1.8 – 0.6	35	0.32
Attitude	0.84	5.5 (1.2)	−0.5	0.1	−3.8**	−0.7 to −0.2	39	0.26
Attitude[a]			−0.5	0.2	−2.6*	−0.9 to −0.1	39	0.13
Positive behavioural beliefs	0.82	4.9 (1.4)	−0.5	0.1	−4.3***	−0.7 to −0.2	35	0.34
Negative behavioural beliefs	0.76	3.2 (1.4)	0.3	0.1	2.7*	0.1–0.6	39	0.14
PBC - capability	0.70	4.9 (1.2)	−0.5	0.2	−3.1**	−0.8 to −0.2	36	0.20
Normative beliefs	0.80	5.5 (1.1)	−0.6	0.2	−3.4**	−1.0 to −0.3	24	0.32
Perceived risk and uncertainty	0.73	2.9 (1.7)	0.4	0.1	4.7***	0.22–0.5	40	0.35
Perceived risk and uncertainty[a]	[a]	[a]	0.6	0.2	3.8**	0.3–1.1	40	0.25

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.
[a] Transformation into tertiles because construct was not a normal distribution.

may be the case that there is some self-selection bias in our sample.

Overall, the results presented here seem to agree with the results of others investigating the effect of antibiotics use on productivity (Emborg et al., 2001; McDowell et al., 2008). However, these authors primarily focused on technical variables rather than economic variables. Therefore, more research is needed on the effects of antibiotics use on the economic performance. The next challenge may be to convince farmers and veterinarians of the limited relationship between economic performance and antibiotics use as a proportion of farmers and veterinarians still see antibiotics as a cost-effective or profitable measure to uphold economic performance of the farm (Coyne et al., 2014; Moreno, 2014; Speksnijder et al., 2015a). In accordance with other literature, our results show that these efforts to decrease antibiotics use can be quite successful without compromising on the economic or technical performance (Rojo-Gimeno et al., 2016; Collineau et al., 2017; Postma et al., 2017).

In the follow-up survey, sow farmers who used more antibiotics were more concerned that low antibiotics use compromises their farm results, perceived more risk and uncertainty, and thought to a lesser extent that they have enough knowledge and time. These results indicate that providing these farmers with knowledge and information on management practices to reduce the use of antibiotics may be helpful. The results of our study revealed that the interviewed sow farmers perceived the veterinarian to be the most important source of information, followed by the feed supplier. The interviewed sow farmers also complied the most to the veterinarian, followed by the feed supplier and the customer. For that reason, it would be useful to focus on continuous involvement of the veterinarian and possibly the feed supplier in providing knowledge about reduction of antibiotics use to sow farmers, preferably by means of individual advice, as the results showed that individual advice was the preferred way to gather knowledge for the interviewed sow farmers. Comparable results were found for broiler farmers by De Lauwere and Bokma (2019). The importance of the veterinarian with regard to the use of antibiotics is also mentioned by Jones et al. (2015). Garforth et al. (2013) placed great importance on access to authoritative information with most seeing veterinarians as the prime source to interpret generic advice from national bodies in the local context. Speksnijder et al. (2015) emphasized the importance of attitudes of veterinarians towards antibiotic use and reduction opportunities. They found that especially experienced veterinarians could be educated about possible risks related to veterinary overuse of antibiotics, while younger veterinarians might require additional support to act independently from farmers' and significant others.

According to Garforth et al. (2013), the main factors that influenced livestock farmers' decision on whether or not to implement a specific disease risk measure are: attitudes to, and perceptions of, disease risk; attitudes towards the specific measure and its efficacy; previous experience of a disease or of the measure; and the credibility of information and advice. In our study, interviewed sow farmers with lower use of antibiotics had a more positive attitude towards keeping or getting antibiotics use under the target value, and perceived less risk and uncertainty. Uncertainty as driver for antibiotics use is mentioned as well in dairy farming with regard to the prevention (Scherpenzeel et al., 2017) and treatment of mastitis (Swinkels et al., 2015). Trujillo-Barrera et al. (2016) found that perceived risk appeared to be a barrier to the adoption of sustainable practices, while risk tolerance appeared to be a positive moderator of the relationship between economic rewards and adoption.

The surveyed sow farmers also had lower scores for negative and higher scores for positive behavioural beliefs and perceived themselves more capable of keeping or getting the use of antibiotics under the target value. Comparable results were found for broiler farmers by De Lauwere and Bokma (2019). Attitude, beliefs and self-efficacy are more often mentioned as drivers to take animal health related measures, for example by Jansen et al. (2010) with regard to mastitis control, Sok et al. (2015, 2016) with regard to a voluntary vaccination programme against Bluetongue, Marier et al. (2016) with regard to Salmonella control and Ritter et al. (2017) with regard to animal disease control programmes.

The study showed that decrease in antibiotics use can be quite successful without compromising on the economic or technical performance, and moreover taking into account farmers' attitudes, perceptions and preferences can be helpful to get a better understanding of farmers' decision making and is useful for the design of tailor-made interventions.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.prevetmed.2020.104981.

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