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Efficiency of measures for sow husbandry: Integrating farm income, animal welfare and public attitudes

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Abstract

*In response to the public's concerns about animal welfare in swine husbandry, the pig (*Sus scrofa domesticus*) sector introduced improved measures to focus on single rather than multiple dimensions of animal welfare concerns without accounting for their impact on public attitudes. These measures failed to improve attitudes to pig husbandry. The present study uses a more comprehensive approach by evaluating animal welfare measures in terms of their effect on animal welfare, farm income and public attitudes. Four measures were defined for each of the following societal aspects of sow husbandry: piglet mortality; tail biting and the indoor housing of gestating sows. A simulation model was developed to estimate the effects of the measures and Data Envelopment Analysis used to compare measures in terms of their effects on animal welfare, farm income and public attitudes. Only piglet mortality measures were found to have a positive effect on farm income but they showed a relatively low effect on animal welfare and public attitudes. The most efficient measure was that which included straw provision, daylight and increased group sizes for gestating sows. The level of improvement of a measure on animal welfare did not necessarily equate to the same level of improvement in public attitudes or decrease in farm income.*

Keywords: *animal welfare, attitudes, efficiency, farm income, measures, pig husbandry*

Introduction

In past decades Western societies have become increasingly concerned about certain aspects of animal welfare, such as pig husbandry (Verbeke & Viaene 2000; Meuwissen & van der Lans 2005; Verbeke 2009; Ingenbleek *et al* 2012; Bergstra *et al* 2017a,b). The response of the pig sector was often to introduce measurable components of physical animal welfare (Beekman *et al* 2002). For example, as regards 'piglet mortality' so-called motherless rearing was introduced, with the primary aim of decreasing mortality rates (Huysman *et al* 1994). Although such measures showed a degree of success, the public continued to harbour a negative attitude towards pig husbandry (Aarts *et al* 2001; Meuwissen & van der Lans 2005; De Greef *et al* 2006; Bergstra *et al* 2017b). This study therefore sought to address the reasons why attitudes toward piglet mortality do not improve if we decrease mortality rates.

Attitudes are determined by moral values (Rokeach 1968–1969), socio-demographic features (Knight *et al* 2004; Boogaard *et al* 2006; Knight & Barnett 2008; Bergstra *et al* 2015) and personal interests (Te Velde *et al* 2002; Bracke *et al* 2005; Boogaard *et al* 2006). Moral values develop through life and are sculpted via a combination of religion, culture, knowledge, education, law and social background (Fraser 1999). One way to differentiate moral values that play a role in animal husbandry is through the following three categories: i) animal conditions should promote good biological functioning; ii) animal suffering should be minimised and contentment promoted; and iii) animals should live relatively natural lives (Fraser 2003). These moral values are weighed against personal factors and interests that are measured against a specific context, eg pig husbandry, to form an attitude (Cohen *et al* 2009). Since the interests of pig farmers and the public differ, both groups will alter in their appraisal of these factors. Pig farmers' interest in animal production (Bock *et al* 2007; van Huik & Bock 2007) and economics (Te Velde *et al* 2002; Bracke *et al* 2005; de Greef & Casabianca 2009; Bergstra *et al* 2017a) means they are more likely to focus on the financial implications of a certain measure. The public, on the other hand, are less concerned with farms' economic status and their greater interest in animal welfare (both physical and mental) as well as human health (Te Velde *et al* 2002; Bergstra *et al* 2017a) sees them focus more on the potential side-effects of measures. For example, regarding the use of antibiotics in pigs, farmers appreciate

the benefits since it positively influences animal production (Cromwell 2002) while the public are more concerned about the possible residual effect of antibiotics in meat on human health (Ngapo *et al* 2003; Huber-Eicher & Spring 2008; Frederiksen *et al* 2010). That pig farmers and the public undoubtedly differ in their moral and personal outlook makes it inevitable that both groups' perception of pig husbandry are also out of sync (Te Velde *et al* 2002; Lassen *et al* 2006; Vanhonacker *et al* 2008; Tuyttens *et al* 2010; Bergstra *et al* 2015).

The failure of pre-existing welfare measures to improve public perceptions coupled with the economic implications of such measures for pig farmers implies a need for new pig husbandry measures to be based on a more comprehensive approach (Bennett 1997; McGlone 2001; Mellor & Stafford 2001). This approach makes it imperative that the effect of such measures on animal welfare, farm income and public attitudes are given due consideration. A number of previous studies on improving welfare in animal husbandry systems have taken only animal welfare and farm income into account (Bornett *et al* 2002; Vosough Ahmadi *et al* 2011; Stott *et al* 2012; Bruijnis *et al* 2013). Ingenbleek *et al* (2012) developed a decision tree to compare the effect of different livestock industry policy instruments on improving animal welfare levels reflecting societal concerns. Although these policy instruments were developed with societal concerns in mind, any comparisons were based purely on their effect on animal welfare (Ingenbleek *et al* 2012). Other studies focused on animal welfare and attitudes via measures of consumers' willingness to pay for animal welfare (Bennett 1997; Glass *et al* 2005; Nocella *et al* 2010; Lagerkvist & Hess 2011; Bennett *et al* 2012; Kehlbacher *et al* 2012). Den Ouden *et al* (1997) calculated the financial costs associated with pig welfare concerns but did not include the effects on welfare. Currently there is a paucity of work looking into an integrated approach whereby animal welfare, farm income and public attitudes are interwoven, although Gocsik *et al* (2013) did set out a largely conceptual approach that included animal welfare, farm income and attitudes.

In our study, we sought to: i) determine the effect of measures to improve welfare in sow husbandry on animal welfare, farm income and citizens' attitudes; and ii) compare the measures in question, in terms of these effects. For the first objective, a simulation model was developed to calculate the effects of measures. For the second, Data Envelopment Analysis, a benchmarking technique, was used to compare the performance of these different measures.

Materials and methods

A simulation model was built in order to help estimate the effects of different measures to improve animal welfare in sow husbandry as well as the effect on animal welfare, farm income and public attitudes. We will seek to explain these measures plus describe a reference farm for measure implementation. Following this there will be a description and parameterisation of the model and then an explanation of measure comparison using Data Envelopment Analysis will be offered.

Table 1 Characteristics of the reference sow farm.

Characteristic	
Farm size (number of sows)	400
Number of litters per sow per year	2.36
Liveborn piglets per litter	13.8
Piglet mortality	13%
Sow replacement rate	43%
Weaning age	26 days
Piglet age when sold	10 weeks
Number of sows per group	20
Number of weaned piglets per group	40
Number of gestation crates	320
Number of farrowing pens	120
Number of weaned piglet pens	50
Surface of sow pen per group	42 m^2
Surface of gestation crate	1.2 m^2
Surface of weaned piglet pen	16 m^2

Source: Agrovision bv (2012).

Measures and reference sow farm

All our measures were specifically related to sow husbandry, ie piglet mortality, tail biting and indoor housing of gestating sows. In the minds of the Dutch public, tail biting and indoor housing are crucial aspects of pig husbandry (Bergstra *et al* 2017b) while piglet mortality has been the subject of much media scrutiny in The Netherlands (Stichting Varkens in Nood 2010; Wakker dier 2010). For each issue, four measures were defined. In order to estimate the effects of measures to improve animal welfare in sow husbandry, a Dutch reference sow farm was defined. It was created using statistics from Agrovision bv (2012), expert knowledge and input from a farmer who owned a pig farm readily comparable to the reference establishment (see Table 1).

Gestating sows are housed in pens with free access stalls for approximately 110 days out of a reproduction cycle of approximately 154 days. Since sows spend more than 70% of their time in such pens, our attention is focused purely on this type of housing. The pen floor consists of 70% solid concrete and 30% slatted concrete. Artificial light is provided for 9 h per day as there is no natural lighting and temperature maintained at 20°C. Gestating sows are fed twice a day in their own feeding troughs and confined in farrowing pens five days prior to farrowing, remaining confined until piglets are weaned. The farrowing pen has a slatted metal floor and a chain for enrichment is provided. When piglets are born they are checked twice daily during sow feeding and provided with a solid-floored area measuring 0.6 m^2 to make a nest. Assistance is offered

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where required, eg if piglets become separated from the sow and/or litter-mates. At 2 to 5 days of age piglets have their tails docked without anaesthesia and receive an ear-tag and the appropriate injections. Once weaned, piglets from several litters are housed together in groups of 40 in pens measuring 16 m^2. Pen floors consisted of 40% solid concrete and 60% slatted concrete and each pen contains two chains for enrichment.

The measures undergoing analysis here were designed in such a way as to allow implementation in the sow reference farm.

The measures to reduce piglet mortality (PM) are described as follows:

PM1 — Camera surveillance farrowing pen

Colostrum intake in the first 48 h of a piglet's life is important to monitor, to ensure enough is taken in for survival (Dyck & Swierstra 1987; Holyoake *et al* 1995; Rooke & Bland 2002; Loncke *et al* 2009) and, to help enable this, surveillance cameras will be installed to monitor the sow and piglets in the first 48 h following parturition. Monitoring is to be carried out every hour (from 0730 until 2130h) and, where necessary, the farmer will enter the farrowing pen to assist piglets in need. One camera can cover two farrowing pens and each week ten cameras will be in use to record the sows that farrow during that time. A monitor inside the stables will need to be provided to enable footage to be viewed, assuming that the farmer of the sow reference farm is already in possession of a monitor inside the house and a smartphone for displaying footage.

PM2 — Providing sows with a jute sack

When sows are able to express nesting behaviour, the odds of piglet mortality decrease (Barnett *et al* 2001; Andersen *et al* 2005). A jute sack can be provided to stimulate nesting behaviour in sows (Hoofs 2012). Hoofs showed that two jute sacks decrease piglet mortality more (0.8%) than one (0.4%). Therefore, two jute sacks will be provided to the sow once she is confined in a farrowing pen. A sack holder will keep the sacks in place close to the sow's head and they will have access to sacks throughout the entire farrowing period.

PM3 — Straw provision for the sow

Nesting behaviour and sow maternal behaviour increases with the provision of straw (Herksin *et al* 1998; Pedersen *et al* 2003) and enhanced maternal behaviour increases piglet reactivity (Herskin *et al* 1998) which leads to improved general awareness and less piglets being crushed (Marchant *et al* 2001). Half a day prior to farrowing, penned sows will receive 300 g straw in their trough each day and the slatting beneath the trough will be replaced by solid flooring to prevent straw from falling into the manure drain.

PM4 — Sow habituation

When sows are not accustomed to being handled by humans it can cause stressful responses and, consequently, a decrease in the number of live piglets (Hemsworth *et al* 1993; Boivin *et al* 2003). When new sows arrive for farrowing at the farm, the farmer, for a week, will spend 2 min with the sow twice a day. During this period the farmer will touch the sow gently on different parts of her body, communicating with her in a calm voice and, as a reward, the sow will be randomly given pellets in her trough or on the floor. These positive interactions will also need to be maintained after the habituation period, for example, by occasionally touching sows while passing through the pens.

Measures to keep tail biting (TB) low were as follows:

TB1 — Tail docking with analgesia

The use of non-steriodal anti-inflammatory drugs (NSAIDs) shortens recovery time after tail docking (Swindle 2008). At least 30 min prior to docking, an NSAID will be injected intradermally using a needleless injection. In The Netherlands, pig farmers are allowed to administer analgesia following a prescription from a veterinarian.

TB2 — Biting material for weaned piglets

Tail biting has been shown to be reduced by environmental enrichment, such as biting material, which decreases harmful social behaviour (Beattie *et al* 2000). Piglets will no longer be tail docked and, instead, weaned piglets will be offered environmental enrichment. To prevent interest in the enrichment being lost (Bracke *et al* 2007), every day each pen randomly receives two of the following enrichment objects: chain, chain with wood, bobbin with rope, chain with rubber and plastic ball. These objects have been shown to positively influence animal welfare (Bracke *et al* 1998; Zonderland 2007). They will be connected to distance holders, which are attached to the pen wall at a height of 100 cm. The function of the distance holders is to ensure that the enrichment objects are placed inside the pen 20 cm from the wall. Zonderland *et al* (2008b) showed that, with provision of one enrichment object, approximately 55% of the piglets had bite wounds on their tails. It is assumed that for measure TB2, 30% of the piglets will have tail-bite wounds.

TB3 — Straw play area for weaned piglets

Tail biting decreases with the provision of straw (Bracke *et al* 1998; Moinard *et al* 2003). Tail docking of piglets will no longer occur and, instead, a straw play area of 6 m^2 will be created on the solid concrete floor of each weaned piglet pen. A bar across the floor will separate this play area from the rest of the pen and every six weeks the straw will be replaced with 5 kg fresh material. It will also be supplemented daily, 10 g per animal. The assumption is that for measure TB3, 20% of piglets will have tail-bite wounds.

TB4 — Chopped straw provision for weaned piglets

Providing a small amount of straw twice daily may decrease tail biting even more than the provision of deep straw (Hunter *et al* 2001). Piglets will no longer be tail docked. Instead, weaned piglets will each receive 10 g chopped straw twice a day. It is assumed that for measure TB4, 10% of piglets will have tail-bite wounds.

Measures to improve indoor housing (IH) of gestating sows were as follows:

IH1 — Free-range outside area

Being able to venture outdoors positively influences animal welfare, increasing natural behaviour (Edwards 2005). An

opening that measures 3 × 1.5 m (width × height) will be made in the outside wall of every gestating sow pen, to provide outside access. Rubber flap doors will seal the passage to prevent indoor temperatures from dropping. The outside enclosure area will measure 42 m^2 and have an iron fence around the perimeter. White sand will cover the floor area, acting as bedding.

IH2 — Straw provision

Access to straw positively influences sow welfare and increases natural behaviour, such as rooting and foraging (Tuyttens 2005). Each gestating sow will receive 100 g daily.

IH3 — Straw provision and daylight

Daylight positively influences animal welfare (Zonderland *et al* 2008a; Winkel & Bokma 2011). Each gestating sow will receive 100 g straw a day and every pen will have an insulated window measuring 2 × 1 m (length × width).

IH4 — Straw provision, daylight and increased group size

Creating larger group sizes so that one group of sows all farrow simultaneously sees more stable groups. The advantage being that groups will be calmer due to a clear social order (Van de Peet-Schwering *et al* 2010).

Groups of gestating sows will be increased from 20 to 100 individuals. To house the sows, five pens will be combined into one and the free access stalls removed. The separate feeding troughs will be replaced by an electronic feeding system with two feeding places in each pen. The one-week system will become a five-week system, meaning that all farrowing pens will be occupied at the same time. Each gestating sow will receive 100 g straw a day and each pen will feature an insulated glass window (4 × 1 m; length × width) inserted into the outside wall.

Simulation model

A simulation model was developed in order to calculate the effects of the different animal welfare measures on farm income, animal welfare and public attitudes. It consisted of an economic module, an animal welfare module and an attitude module.

The economic module calculated farm income (€ per year):

FI = TRE–TCO, where TRE refers to total revenues and TCO to total costs. The total revenues were calculated by: TRE = PP × NL × (LZ–LZ × PM) + SS × RS/(100%–SB) × SP × (RS–SB), where PP was price per piglet, NL was number of litters, LZ was litter size, PM was piglet mortality, SS was selected breeding sow price, RS was replacement breeding sows, SB was selection breeding sow before first insemination and SP was sow price. The total costs were calculated by: TCO = TBC + TAC + TFC + TLC + TOC, where TBC was total building costs, TAC was total animal costs, TFC was total feed costs, TLC was total labour costs and TOC was total other costs. The total building costs were calculated by: TBC = IB × CS/OP × CS/DI + IB × CS/OP × CS × MI, where IB was investment building and inventory, CS was company size, OP was occupation (percentage sows regarding sow places), DI was depreciation period investment and MI was market interest. The total animal costs were calculated by: TAC = BP × (RS/[100%–SB]) + (SP + [SP + LZ × (1–PM) × PP]/2) × MI, where BP was breeding sow price. The total feed costs were calculated by:

TFC = SF/100 × SI + PF/100 × PI × NL × (LZ–LZ × PM) + (SF/100 × SI + PF/100 × P1 ×NL × [LZ–LZ × PM]) × MI/52, where SF was sow feed price, SI was sow feed intake, PF was piglet feed price and PI was piglet feed intake. The total labour costs were calculated by:

TLC = CS × OP × Σ(CP × CF × CA × CW × TD × CC × OT) × LP, where CP was time to clean sow pens, CF was time to clean farrowing pens, CA was time to clean farrowing pens after weaning, CW was time to clean weaned piglet pens, TD was time to dock piglet tails, CC was time to check piglets in the first 48 h, OT was time for other tasks and LP was labour price. Total other costs were calculated by:

TOC = Σ(HC × TC × HE × LI × PA × CA × JS × ST × EE × AN × OC), where HC was healthcare costs, TC was transport costs for piglets, HE was heating costs, LI was lighting costs, PA was pen adjustment costs, CA was camera costs, JS was jute sack costs, ST was straw costs, EE was environmental enrichment costs, AN was analgesia costs and OC was other costs.

The animal welfare module calculates the total animal welfare score for a farm:

$$TWS = \sum_{i=1}^{27} (AWS_i)$$

where AWS_i refers to animal welfare score for animal welfare feature *i* of the 27 animal welfare features. These 27 features were assigned to the animal welfare module based on features used in Welfare Quality® (Botreau *et al* 2007; Blokhuis 2008). From the 12 Welfare Quality® criteria, only those that were relevant for the measures defined in our study were implemented. As Welfare Quality® does not focus on piglet welfare, features for piglet welfare were added. All criteria and features used in our model can be found in Appendix I (see supplementary material to papers published in *Animal Welfare*: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Each animal welfare feature received a score between 1 (worst) and 100 (best), which made the maximum possible 2,700. To calculate the animal welfare score, separate formulae were developed. The features water supply (WS) and number of clean drinking spots (CD) were combined to make an animal welfare score for water supply: AWSW = 100/WS × CD.

The animal welfare score for number of sows per drinking spot was calculated with: AWSD = 1/(PD × n*a*) × 100, where n*a* is the number of animals per drinking nipple and PD is the expected percentage of animals per drinking nipple that have drinking needs at the same time. For feature parameters with two categories, ie stereotypies sow (Appendix I: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material), the percentage for category '0' was the animal welfare score. For all feature parameters with three categories, such as bursitis and sow lameness, the animal welfare score was calculated with:

AWSX = C0–C2/10/2, where C0 was the percentage assigned to category '0' and C2 was the percentage assigned

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to category '2'. The percentage assigned to the features mortality and explorative behaviour was also the animal welfare score. The percentage assigned to the features mortality and positive social behaviour was subtracted from 100 to become the animal welfare score. The animal welfare score for surface per sow was calculated by:

AWSS = $(F_s – m)/F_s \times 100$, where F_s refers to feature score for surface per sow and is the legal minimum surface, which is 2.1 m^2 in The Netherlands. For group size it was assumed that ≥ 100 animals per group was optimal for animal welfare, meaning that the number of animals per group up to 100 is the animal welfare score and groups of 100 or more animals is 100%. Tail docking received an animal welfare score of 0 when tails were docked without sedation, a score of 25 when tails were docked with either pre- or post-operative analgesia, a score of 50 when tails were docked with both pre- and post-operative analgesia and a score of 100 when tails were not docked at all. The qualitative behavioural assessment score could receive a feature score between –8 and 8, which is a range of 16. For the animal welfare score of the qualitative behavioural assessment score, the percentage of the feature score on the 16 scale was used. For example, a feature score of –5 would be a score of 3 on the 16 scale which is 18.8% and thus an animal welfare score of 18.

The attitude module was based on the work of Bergstra *et al* (2017a) who studied the attitude of the public towards different entities, ie animals, humans and the environment, with regard to sow husbandry. The attitudes toward all these entities was included in this study because it has been shown that it's not only animal welfare that is important when considering public perception of pig husbandry (Kanis *et al* 2003; Meeuwissen & van der Lans 2005; Boogaard *et al* 2011b). Respondents to a previously held questionnaire assigned additional care levels (Bergstra *et al* 2017a) to aspects related to animal mortality, litter size, farmers' income, public health risks and environmental waste. These additional care levels indicated the extra attention respondents considered necessary for assessing current sow husbandry and are representative of the negative attitudes toward this practice. In the attitude module of our simulation model, 25 aspects were included for which additional care levels were translated into negative attitude scores on a scale of 1 (no negative attitude) to 5 (maximum negative attitude). A total attitude score was calculated by: $TAS = TAS_{max} – NAS$, where TAS_{max} was the maximum possible total attitude score and NAS was the total negative attitude score. The maximum possible total attitude score in this case was 125; 25 aspects times the maximum possible score of 5 (negative attitude scores reversed). For each animal welfare measure the total negative attitude score was calculated by:

$$NAS = \sum_{i=1}^{25} (\Delta NA_i \times IS + NA_{r\,i})$$

where ΔNA is the difference in negative attitude score for aspect *i* of the 25 aspects between the reference farm and after measure implementation, IS is an importance score assigned to each measure in relation to the relevant issue (ie piglet mortality, tail biting and indoor housing) and NA_r is the negative attitude level for the reference farm *r* for aspect *i*. The importance scores were based on results from Bergstra *et al* (2017a). Bergstra *et al* (2017a) showed percentages of Dutch citizens that found certain issues of sow husbandry acceptable, not acceptable or if they had no judgment. It was assumed that when citizens had no judgment, they had no opinion about the issue (because of, for example, lack of knowledge) and, thus, the issue was of no concern to them. When they found an issue unacceptable this indicates that it was an issue of concern. It was assumed that the higher percentage of citizens that found an issue unacceptable, the higher the importance of that issue with regard to public attitudes. For the issue 'piglet mortality', the majority of respondents (64%) had no judgment, but 21% indicated this to be unacceptable, which resulted in an importance score of 0.21 for piglet mortality. The issue 'tail biting' was not addressed in the study of Bergstra *et al* (2017a). However, respectively, 60 and 83% of citizens indicated that they found tail docking and interventions without sedation unacceptable. Both issues are strongly related to tail biting and, therefore, the average of these percentage respondents (0.71) was used for the importance score for tail biting. For the issue 'indoor housing', 69% indicated that they found this unacceptable, resulting in an importance score of 0.69 for indoor housing.

Parameterisation

The calculations in the economic module were based on several farm inputs, eg technical numbers, such as farm size and piglet mortality, investments and animal prices. Default values were assigned to the reference farm, based on the Dutch animal husbandry handbook with price information (KWIN-Veehouderij 2013/2014), a database with official yearly numbers for the pig sector, eg litter size and mortality rate (Agrovision bv 2012), and input from a farmer with a sow farm comparable to the reference farm, ie number of sows, group sizes, number of gestation crates and farrowing pens, and working time per activity. The exact sources per value are provided in Appendix II (see supplementary material to papers published in *Animal Welfare*: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). To the few inputs that were not valued based on available information, a value was assigned based on our own expertise. For each measure it was determined, based on the knowledge of experts in economics and animal production systems, which inputs would change after measure implementation. The calculations were carried out using numbers from literature, experts' input and numbers provided by companies selling products and equipment needed for the defined measures (see Appendix III in supplementary material to papers published in *Animal Welfare*: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). These changes with regard to the default situation were processed in the economic module to calculate the farm income after implementation of each measure. We included a variation in inputs because the

effect of animal welfare measures on the use of inputs is uncertain and, thus, the effect on farm income may vary. This variation was based on an input change of 5%. A description of changing inputs, and inputs and variation can be found in Appendix IV (https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material).

For the animal welfare module, default scores were assigned to the feature parameters for the reference farm, based on average scores for a sow farm in The Netherlands (Vermeer *et al* 2012). For each measure it was decided which features would change with regard to the default situation after measure implementation. For these features, the animal welfare scores were adjusted. The animal welfare score for water supply only changed for measure IH4, where the number of available drinking nipples per animal changed from 1:1 to 10:1. It has been shown that pigs usually start drinking after eating and consume 30% of their daily water intake at that moment (Yang *et al* 1981). Based on this finding and the availability of two feeding troughs and ten drinking nipples, we assumed the percentage of animals per drinking nipple that have drinking needs at the same time to be 13%. In our model, we included a variation for animal welfare scores because it is uncertain the effects of these measures on animal welfare. The animal welfare scores and the variation can be found in Appendix V (see supplementary material to papers published in *Animal Welfare*: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material).

For the attitude module, the results on additional care levels that citizens assigned to aspects of sow husbandry from the study of Bergstra *et al* (2017a) were used. The average of these additional care levels was used as negative attitudes scores for the default situation in the present study. The aspects toward which attitudes were expected to change after implementation of one of the defined measures were selected. To each of these aspects the change in negative attitude with regard to the default situation and the variation was indicated based on our expertise (Appendix VI, see supplementary material to papers published in *Animal Welfare*: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material).

Comparing measures — Data Envelopment Analysis

In this study we used Data Envelopment Analysis (DEA) to compare the effect of measures for sow husbandry on animal welfare, farm income and attitudes toward sow husbandry. DEA is a non-parametric linear programming technique for assessing the productive efficiency of a group of producers, such as pig farmers, referred to as decision-making units (DMUs) (Martić *et al* 2009; Huijps *et al* 2010). For each producer, a benchmark is constructed based on a set of common inputs that generate a set of common outputs (Martić *et al* 2009; Huijps *et al* 2010). DEA can also be used to compare measures with multiple inputs and outputs (see, for example, Huijps *et al* 2010) which is the case in our study.

The DEA model distinguishes one input (total costs) which produces three outputs, ie total revenues, animal welfare and attitude. The input and three outputs were obtained from the modules for farm income, animal welfare and attitude of our simulation model. An output-oriented DEA was used, which implies that the DEA model radially expands the three outputs (with equal proportions) for a given level of input used. The efficiency frontier consists of the best practice farms and was calculated under the assumption of variable returns to scale (VRS). The VRS assumption ensures that each farm is compared with best practice farms of a similar size. The radial distance of a DMU from the efficiency frontier indicates the technical efficiency of this DMU. Technical efficiency F for DMU o was calculated as:

$$\text{Max } F$$

$$F, \lambda^1, \ldots \lambda^K$$

Subject to

$$x^o \geq \sum_{k=1}^{K} \lambda^k x^k$$

$$Fy^o \leq \sum_{k=1}^{K} \lambda^k y^k$$

$$\sum_{k=1}^{K} \lambda^k = 1$$

where K indicates the number of DMUs. DEA was carried out with: i) impact on all three outputs; ii) impact on animal welfare and attitudes; and iii) impact on only attitudes.

Since the input and outputs for DEA were stochastic variables, for each measure DEA was run 1,000 times with random values from a uniform distribution for the input and each output. The minimum and maximum values for the uniform distribution were obtained from our simulation model. From the 1,000 DEA runs, the averages and 95% confidence intervals were calculated. DEA was run in R version 3.0.0 (2013) and the averages and confidence intervals calculated with IBM SPSS Statistics 20 (IBM Corporation, New York, US).

Results

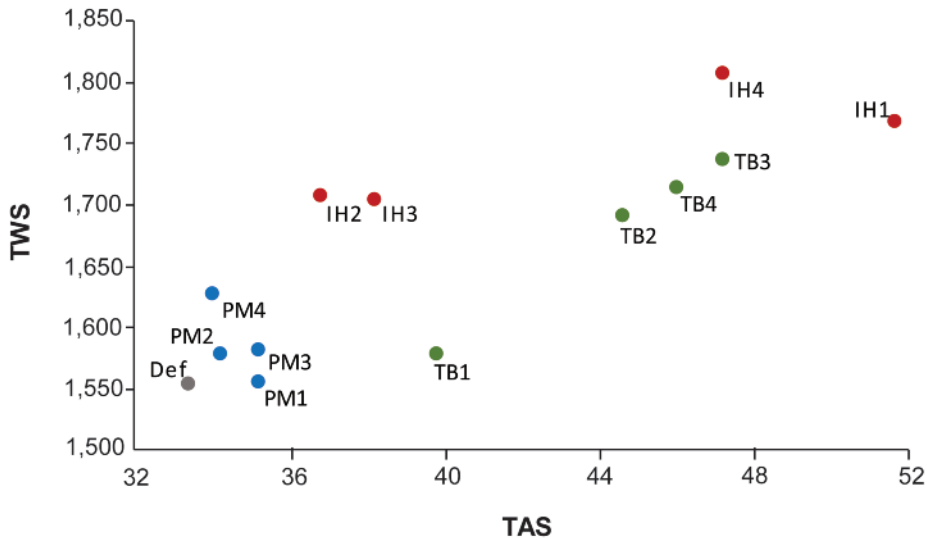
Effects of measures on animal welfare, farm income and public attitudes separately

The effect of different measures for sow husbandry on farm income, animal welfare and public attitudes toward sow husbandry were computed. The means and variation of these effects for the default situation and after implementation of the different measure are shown in Table 2 (see supplementary material to papers published in *Animal Welfare*: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material).

For the default situation, fixed numbers without variation were calculated. The measures for piglet mortality were the only measures with a positive effect on farm income, total costs and total revenues. The effect of the measures for piglet mortality on animal welfare and attitudes was low compared to the other measures, except for tail docking with analgesia (TB1). The latter had a slightly higher score for attitude, but an equal animal welfare score compared to the measures for piglet mortality. A straw playing area for weaned piglets (TB3) had the highest negative effect on farm income with the highest total costs compared to the other measures. The animal welfare and attitude score of TB3 was relatively high. The highest animal welfare and attitude scores were given to measures for indoor housing of gestating sows (IH). Free-range outside housing (IH1)

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Figure 1



The effects of measures for sow husbandry on animal welfare and attitudes; total animal welfare scores (TWS) and total attitude scores (TAS) of the default situation (Def) and the different measures for sow husbandry. Explanation abbreviations of measures: PM: piglet mortality, TB: tail biting, IH: indoor housing gestating sows, PM1: camera surveillance farrowing pen, PM2: jute sack provision sow, PM3: straw provision sow, PM4: sow habituation, TB1: tail docking with analgesia, TB2: biting material for weaned piglets, TB3: straw playing area for weaned piglets, TB4: chopped straw provision for weaned piglets, IH1: free-range outside area, IH2: straw provision, IH3: straw provision and window and IH4: straw provision, window and increased group size.

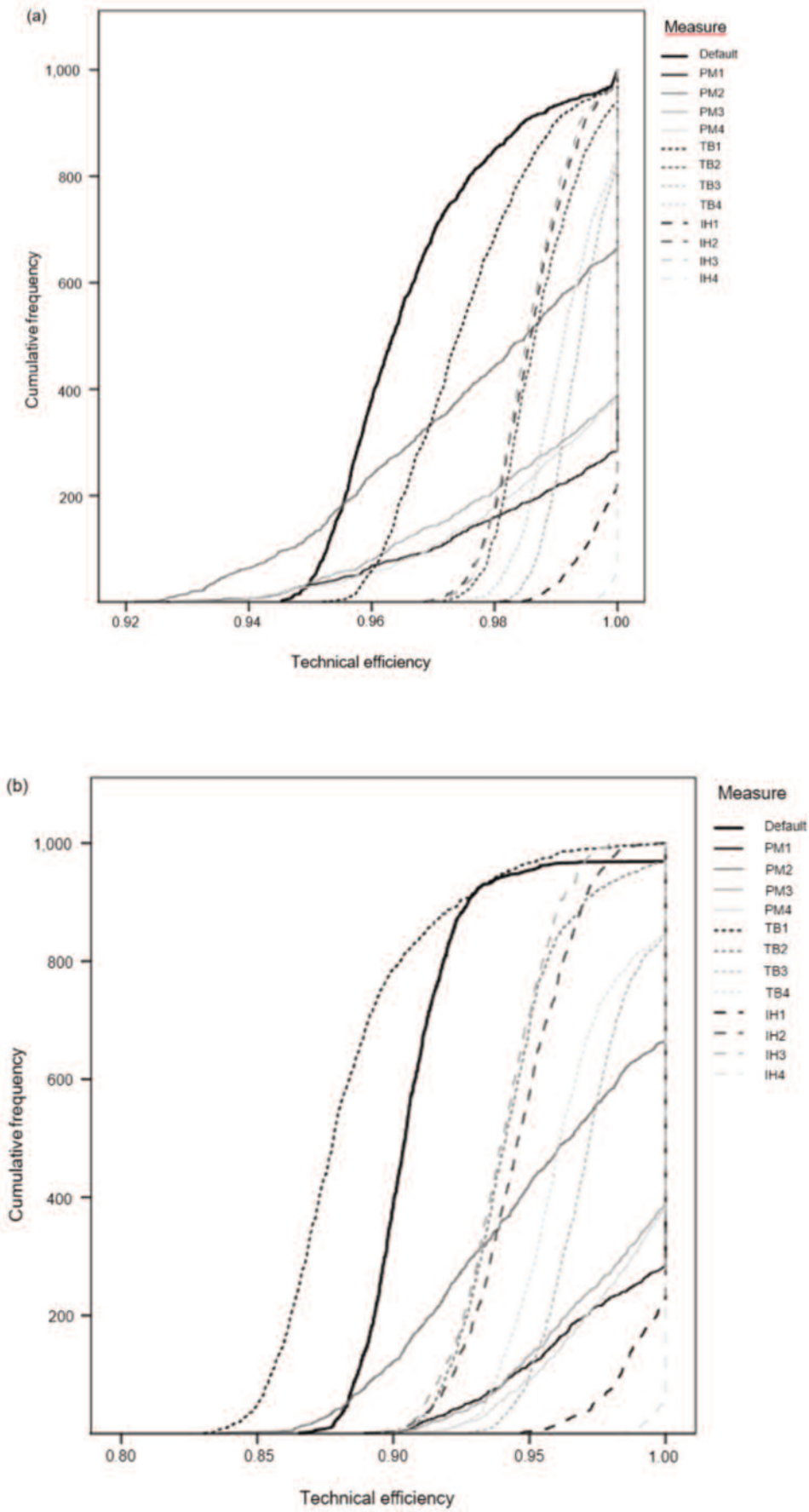
received the highest attitude score compared to the other measures and the second highest animal welfare score. The measure 'straw provision, daylight and increased group size' (IH4) received the highest animal welfare score compared to the other measures and the second highest attitude score. The total effects on animal welfare and attitude of the default situation and the different measures are shown in Figure 1. The effects on animal welfare were comparable for biting material for weaned piglets (TB2), chopped straw provision for weaned piglets (TB4), straw provision (IH2) and straw provision and daylight (IH3), but the effects on attitudes were different, especially between the tail-biting measures and indoor housing measures (Table 3 [see supplementary material to papers published in *Animal Welfare*: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material] and Figure 1).

Combined effects of measures

To compare the combined effects of measures to improve animal welfare in sow husbandry on animal welfare, farm income and attitudes toward sow husbandry, technical efficiencies were calculated with DEA. The input 'total costs' and outputs 'animal welfare scores' and 'attitude scores' for DEA were derived from our simulation model. Mean technical efficiencies and the 95% confidence intervals of the 1,000 DEA runs per measure are shown in Table 3 (https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material).

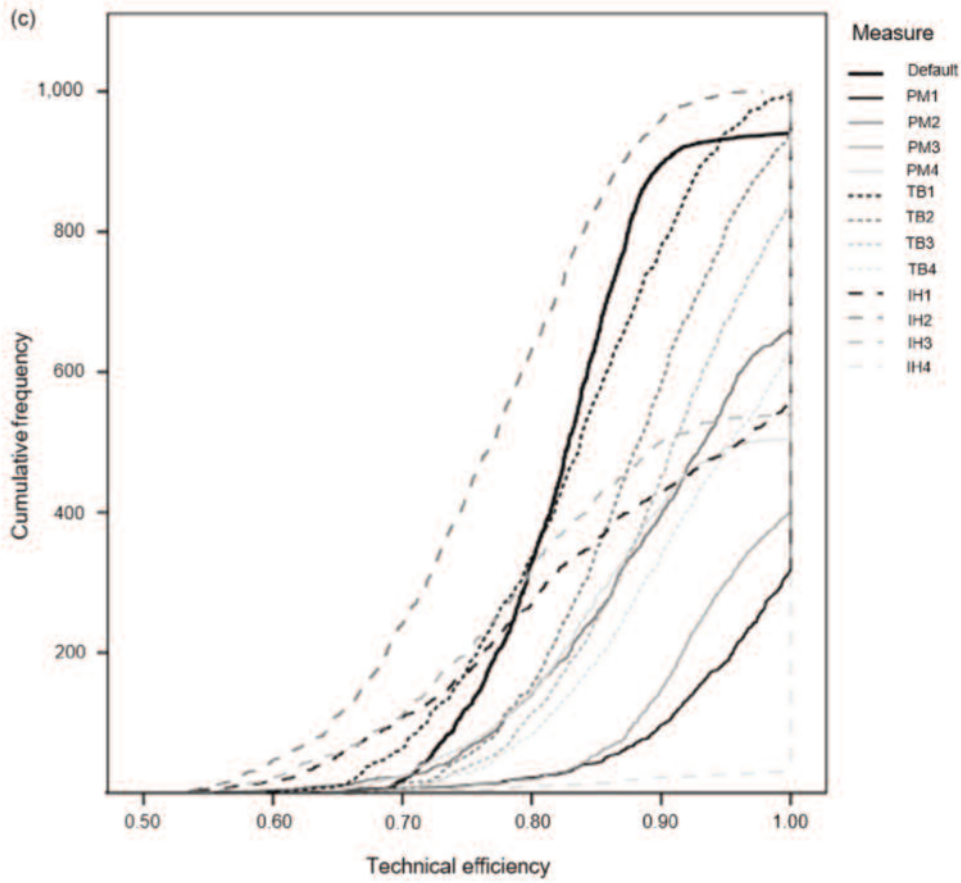
The default situation was, on average, inefficient for the three different impacts used in DEA. When DEA used the impact on farm income, animal welfare and attitudes, the default situation was most inefficient compared to situations in which one of the measures was implemented. The measure 'straw provision, window and increased group size' (IH4) was the only measure that was fully efficient when DEA used the impact on farm income, animal welfare and attitudes and the impact on animal welfare and attitudes. When DEA used the impact on only attitudes, none of the measures was fully efficient but measure IH4 was the least inefficient compared to the other measures and the default situation. The free-range outside area (IH1) was, after measure IH4, the least efficient for all impacts. The technical efficiency scores were generally lower when DEA used the impact on only attitudes compared to the other impacts. When this impact was used, the lower and upper bound of the confidence intervals were further apart compared to the other impacts. The variation in technical efficiency was also highest when DEA used the impact on only attitudes (Figure 2[a]) compared to the other impacts (Figure 2[b] and [c]). The variation in technical efficiencies was lowest when DEA used the impact on both, farm income, animal welfare and attitudes (Figure 2[a]) compared to the other impacts (Figure 2[b] and [c]). For all three impacts that DEA used, measure IH4 showed the least variation and was first-order stochastically dominant over all other measures and the default situation (Figure 2). When DEA used the impact on both, farm income, animal welfare and attitudes and on-farm income and attitudes (Figure 2[a] and [b]), measure IH1 was first-order stochastically dominant over all other measures, except measure IH4, and the default situation but when DEA used the impact on attitude (Figure 2[c]), measure IH1 was only

Figure 2



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Figure 2 (cont)



The variation in technical efficiency (TE) resulting from 1,000 runs in Data Envelopment Analysis under variable returns to scale with impact on (a) farm income, animal welfare and attitudes, (b) animal welfare and attitudes and (c) attitudes for the default situation and measures for sow husbandry. Measure abbreviations: PM: piglet mortality, TB: tail biting, IH: indoor housing gestating sows, PM1: camera surveillance farrowing pen, PM2: jute sack provision sow, PM3: straw provision sow, PM4: sow habituation, TB1: tail docking with analgesia, TB2: biting material for weaned piglets, TB3: straw playing area for weaned piglets, TB4: chopped straw provision for weaned piglets, IH1: free-range outside area, IH2: straw provision, IH3: straw provision and window and IH4: straw provision, window and increased group size.

stochastically dominant over three other measures and the default situation. When DEA used the impact on farm income, animal welfare and attitudes, all measures were first- or second-order stochastically dominant over the default situation. When DEA used the impact on animal welfare and attitudes, the default situation was second-order stochastically dominant over measure TB1. When DEA used the impact on attitude, the default situation was first-order stochastically dominant over measure IH2 and second-order dominant over measure TB1.

Discussion

The objectives of this study were to: (i) determine the effect of measures for the improvement of animal welfare in sow husbandry on animal welfare, farm income and public attitudes; and (ii) compare these measures with regard to the effects. These effects were computed using a simulation model that included three modules, ie an economic, an animal welfare and an attitude module. Then, farmers' economic interests (Bracke *et al* 2005; Bergstra *et al* 2017a), the public's animal welfare interests (Bergstra *et al* 2017b) and the effects on public attitudes were addressed. In the attitude module, attitude aspects described in Bergstra *et al* (2017b) were included. Bergstra *et al* (2017b) showed that the wide range of factors related to animals, humans and the environment that they described, such as mortality and pain in animals, income for animal keepers, public health risks and environmental waste, play an important role in the public's attitude towards sow husbandry in The Netherlands. All these aspects, therefore, need to be considered when assessing the effect of measures to improve animal welfare in sow husbandry on public attitudes. We focused on this wide range of aspects and included those deemed relevant, as based on our expertise, for the measures defined in our model. We decided to include the general attitude of the public towards sow husbandry as opposed to their attitudes toward specific welfare measures, since we were interested in what these measures would do to the overall view the public have of sow husbandry. For the measures, the effects on animal welfare, farm income

and public attitudes were simulated, on the basis of a default situation — a reference sow farm considered to be representative of The Netherlands. For each of these measures, total efficiencies were calculated based on their effects on animal welfare, farm income and public attitudes with data envelopment analysis (DEA). We decided to use DEA because this method allowed integration of various impacts into one overall score, ie efficiency. For the effects on attitudes, weights were included per animal welfare measure. This was because Bergstra *et al* (2017b) showed that opinions about the issues to which the measures relate differ. It was assumed that measures related to an issue with greater concerns would affect the public's attitude toward sow husbandry more than measures related to issues with lower concerns. For the effects on income and animal welfare no weights were included. In terms of income, each feature either has an effect on cost/revenues or has no effect. For animal welfare, it becomes more complicated because one feature can have a stronger effect on total animal welfare than another. In Welfare Quality®, different calculations were used due to variation in the importance of the features (for a description of the calculations, see Welfare Quality® 2009). Here, the use of a 100-scale enabled the subtle effects of welfare measures to be perceived. Therefore, it was decided not to use weights for each feature.

This study focused on the issue of sow husbandry in The Netherlands. However, regarding pig production, The Netherlands serves as an important export hub, sending produce to Germany, Italy and the UK (LTO Nederland 2005–2006): thus, sow husbandry in The Netherlands also impacts citizens and consumers of other countries. Furthermore, intensification of animal husbandry systems in relation to animal welfare is a topic of discussion throughout the European Union (Van der Meulen *et al* 2011) with most Europeans believing animal welfare in these systems to be between moderate and very bad (Verbeke 2009) and these animals in need of better protection (Eurobarometer 2016). The model presented here can also be of use to other countries since inputs are able to be customised for other countries.

Our results showed that the effects of measures for sow husbandry on farm income, animal welfare and attitudes differed. This means that, for example, the level of welfare improvement does not necessarily lead to a proportionate level of improvement in public attitudes, ie one effect cannot predict the other effects. Previous work looking into the economic consequences of improvements to welfare in different farm animals also concluded that any improvements did not necessarily correlate with economic effects (Cain & Guy 2006; Vosough Ahmadi *et al* 2011; Stott *et al* 2012; Bruijnis *et al* 2013; Seddon *et al* 2013). However, studies that sought to assess the attitude of the public or consumers through their willingness to pay for welfare improvements noted that there was a positive correlation. There was a willingness to pay more for products where animals had higher welfare (Bennett 1997; Glass *et al* 2005; Nocella *et al* 2010; Lagerkvist & Hess 2011; Bennett *et al* 2012; Kehlbacher *et al* 2012; Eurobarometer 2016). This would indicate that improvements in welfare positively affect willingness to pay and, by association, show a positive economic effect. However, other studies have questioned the notion of willingness to pay (Korthals 2001; Carlsson *et al* 2004; Vanhonacker *et al* 2007). The public are happy to answer questionnaires, indicating a willingness to invest in animal welfare but, often, as consumers they do not show the same investment in animal welfare (Aarts & Te Velde 2001). So, the question remains as to what extent willingness to pay genuinely affects economics. This would be interesting to assess in future studies.

Willingness to pay for animal welfare appears not to relate to the public's attitudes toward measures to improve animal welfare that are implemented in sow husbandry (Glass *et al* 2005). This is probably because the public weigh their moral values, personal values and interests with regard to animal welfare differently to pig farmers (Cohen *et al* 2009) and pig farmers decide to a great extent which measures are implemented. Conventional pig farmers focus on animal production and their primary focus is on animals' physical health (Bock *et al* 2007; Van Huik & Bock 2007) and the economic consequences of a measure (Te Velde *et al* 2002; Bracke *et al* 2005; De Greef & Casabianca 2009; Bergstra *et al* 2017a). When a measure improves an animal's physical health, it improves production and, consequently, positively affects farm income. If such an improvement is viable for a pig farmer, he or she will support that measure. The public focus both on the physical and mental sides of animal welfare (Te Velde *et al* 2002) and consider the side-effects of measures on animals. For example, take the use of farrowing pens to decrease piglet mortality, the public will consider the restriction of movement imposed on the sows and, therefore, reject such a measure (Boerderij 2018). This means that a measure with a positive effect on physical animal welfare will not get the support of the public since, from a moral perspective, they will view it as negatively affecting animal welfare (eg natural behaviour). To gain public support for animal welfare measures, their attitudes should be considered, not their willingness to pay. In defining willingness to pay it is likely that, besides animal welfare, other aspects will be used as indicators, such as food safety, healthiness, type of product and quantity (Harper & Henson 2001; Svedalis & Harvey 2006; Hudson 2010; Bennett *et al* 2012). Not all of these aspects are relevant in terms of animal welfare. When including attitudes toward sow husbandry in the development of animal welfare measures the relevant aspects — those related to animal welfare, human health and the environment (Verbeke & Viaene 2000; Meuwissen & van der Lans 2005; Bergstra *et al* 2017b) — will be included. This will provide a clear picture of what effects these measures will have on attitudes toward sow husbandry.

That a positive effect of measures to improve animal welfare in sow husbandry does not necessarily lead to an equivalent improvement in the public's attitude makes it essential to view the effects of these measures on animal welfare and public attitudes, separately. This study is the first to make this distinction and uses a more comprehensive

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approach by including animal welfare, farm income and public attitudes. This comprehensive approach enabled different effects of measures to improve animal welfare in sow husbandry to be integrated into a single metric (Van den Besselaar & Heimeriks 2001). In developing measures for sow husbandry, the sector focuses only on the effects on animal welfare and farm income. As the effect on public attitude is not included, it is an approach doomed to fail.

Our study has shown that the pig sector's approach delivers an altogether different perception of a measure's efficiency compared to the more comprehensive approach deployed here. For example, the defined measures for piglet mortality were the only ones with a positive effect on animal welfare, farm income and attitudes. Based on that information, those measures appear to be more efficient than the other defined measures. However, with the approach used here, it became clear that the measure 'straw provision, daylight and increased group size for gestating sows' was the most efficient measure overall and that the measures for piglet mortality were, overall, inefficient. These differences in efficiency were a result of the greater effect of 'straw provision, daylight and increased group size for gestating sows' on animal welfare and public attitudes compared to the measures for piglet mortality. The greater effect on public attitudes can be attributed to the public placing greater importance on animals being provided with daylight and space (Boogaard *et al* 2011b) which was part of this measure's focus. Furthermore, Bergstra *et al* (2017b) showed that the Dutch public did not have an opinion on piglet mortality, a finding which might explain the low effect of measures for piglet mortality on public attitudes. The greater effect on animal welfare of the measure 'straw provision, daylight and increased group size for gestating sows' can be explained by more features in the animal welfare module being affected by this measure compared to the measures for piglet mortality (Appendix V; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material).

When DEA used the impact only on attitudes, the efficiency scores were lower and the confidence intervals larger for all measures compared to when DEA used the impact on animal welfare and attitudes or on animal welfare, attitudes and farm income. This indicates a greater uncertainty regarding the effect on attitudes. This uncertainty is reflected in the relatively high variation in the effect of measures to improve animal welfare in sow husbandry on attitudes compared to the effects on farm income and animal welfare. The attitude effects are uncertain because public attitudes are influenced by several factors, such as socio-demographic features (Knight *et al* 2004; Boogaard *et al* 2006; Knight & Barnett 2008; Bergstra *et al* 2017b), personal interests (Te Velde *et al* 2002; Bracke *et al* 2005; Boogaard *et al* 2006) and the media (Boogaard *et al* 2006, 2011a; Knight & Barnett 2008). These factors define how the public weigh their moral values against other personal values in forming an attitude (Cohen *et al* 2009) toward, in this case, sow husbandry. Attitudes change over time due to changing technologies, new ideas about animal husbandry and greater public interest in food production methods (Chrispeels & Mandoli 2003). As a result of these changes and uncertainty as to what will be presented in the media, it is difficult to predict the extent to which attitudes will change. When the public fail to be informed about these measures they are unaware of changes made and will not change their attitudes toward sow husbandry. A variety of different methods provide this information, such as presenting it as a news item or disseminating it via social media (Rutseart *et al* 2014). Which methods are the best is a discussion in its own right and beyond the scope of this study.

The effects of measures to improve animal welfare in sow husbandry on public attitudes were low. Despite this, it may still be worthwhile implementing the most efficient measures because they improve public attitudes. Improving public attitudes, however subtly, may improve the image of the pig sector. One reason for the relatively small effect of these measures on public attitudes is perhaps that the defined measures are developed for implementation on an existing sow farm. Making changes to an existing farm may not affect animal welfare in a way the public seek. Rebuilding a farm to improve the welfare may be appealing to the public but it is inevitably associated with higher costs. A number of new housing designs have been developed that could possibly alter public attitudes, making them more favourable toward the husbandry system in question, such as 'Vair varkenshuis' (Vair 2014) and 'Comfort Class' for pigs (De Greef *et al* 2011), 'Rondeel' for laying hens (Van Niekerk & Reuvekamp 2011) and 'Koeientuin' for cows (Galama *et al* 2009). These designs have been developed to replace existing farms and involve high investment costs, resulting in greater production costs (Galama *et al* 2009; Van Niekerk & Reuvekamp 2011). A possible risk is for these higher costs to result in an overall inefficiency when the effects on animal welfare, farm income and attitudes are integrated. That means that the higher costs outweigh the effect on animal welfare and/or attitudes. So, all these effects should be given consideration.

In order to improve public attitudes toward sow husbandry it is necessary to find measures that are efficient in their overall effect on animal welfare, farm income and public attitudes. This paper allows such measures to be identified and the findings allow policy-makers and farmers to take further steps. For example, taxes may be reduced or subsidies provided for efficient measures, to stimulate farmers to implement these measures.

Conclusion

A simulation model was created to estimate the effects of different measures for sow husbandry welfare, farm income at farm level and public attitudes. The model allows different effects to be integrated and overall efficiencies to be calculated. This study is the first to integrate these effects.

The results showed that the effects of the defined measures to improve animal welfare in sow husbandry were different for animal welfare, farm income and public attitudes. This means that one effect cannot predict the other effects. Our findings indicate that it is essential to use a more compre-

hensive approach for evaluating animal welfare measures that integrate animal welfare, farm income and public attitudes. The most efficient measure in this study, ie 'straw provision, daylight and increased group size for gestating sows', still had a rather low effect on public attitudes. To determine measures with a greater effect on these attitudes, further research is required and a basis for this research is provided by our study.

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