The Old School, Brewhouse Hill, Wheathampstead,
Hertfordshire AL4 8AN, UK
www.ufaw.org.uk

Animal Welfare 2020, 29: 433-447
ISSN 0962-7286
doi: 10.7120/09627286.29.4.433

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

TJ Bergstra*†, H Hogeveen†, EN Stassen‡ and AGJM Oude Lansink†

† Department of Social Sciences, Chair Group Business Economics, Wageningen University, Hollandseweg 1, 6706 KN Wageningen, The Netherlands

‡ Department of Animal Sciences, Chair Group Animals in Society, Wageningen University, De Elst 1, 6708 WD Wageningen, The Netherlands

* Contact for correspondence: tamarabergstra@hotmail.com

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

https://doi.org/10.7120/09627286.29.4.433 Published online by Cambridge University Press

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

https://doi.org/10.7120/09627286.29.4.433 Published online by Cambridge University Press

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:

$$\max_{F,\ \lambda^1,\dots\ \lambda^K} F$$

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

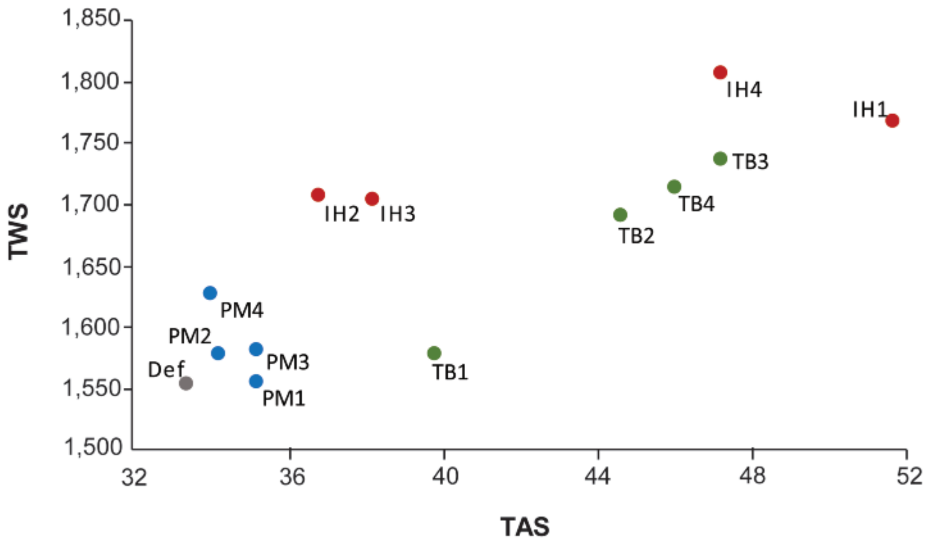
Effects of measures on animal welfare, farm income and public attitudes separately

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)

https://doi.org/10.7120/09627286.29.4.433 Published online by Cambridge University Press

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.

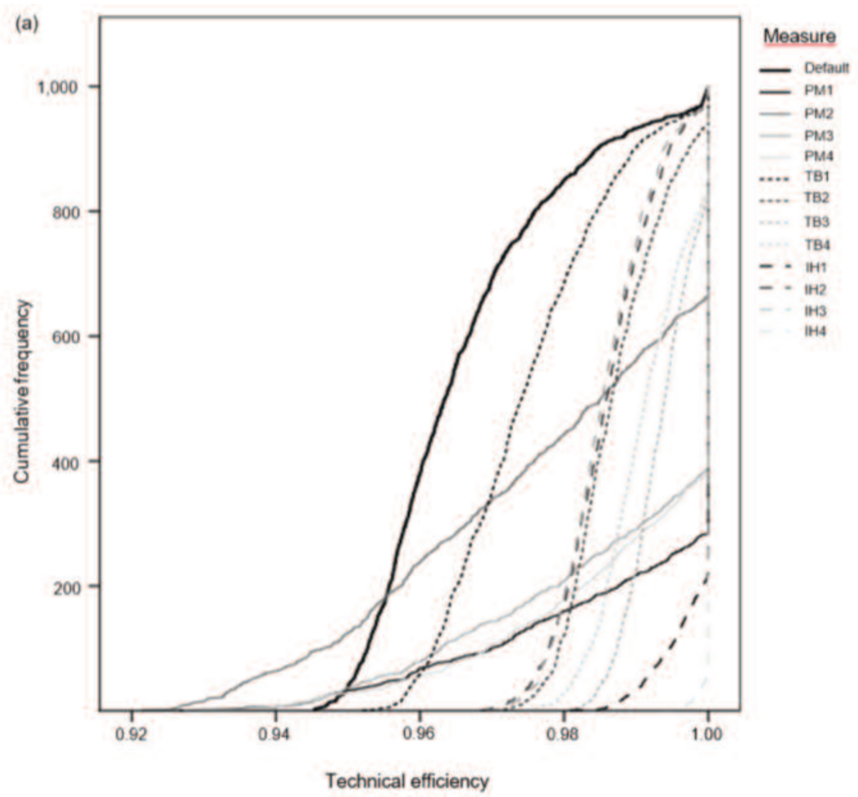
received the highest attitude score compared to the other measures and the second highest animal welfare score. The measure 'straw provision, daylight and increased group size' (IH4) received the highest animal welfare score compared to the other measures and the second highest attitude score. The total 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).

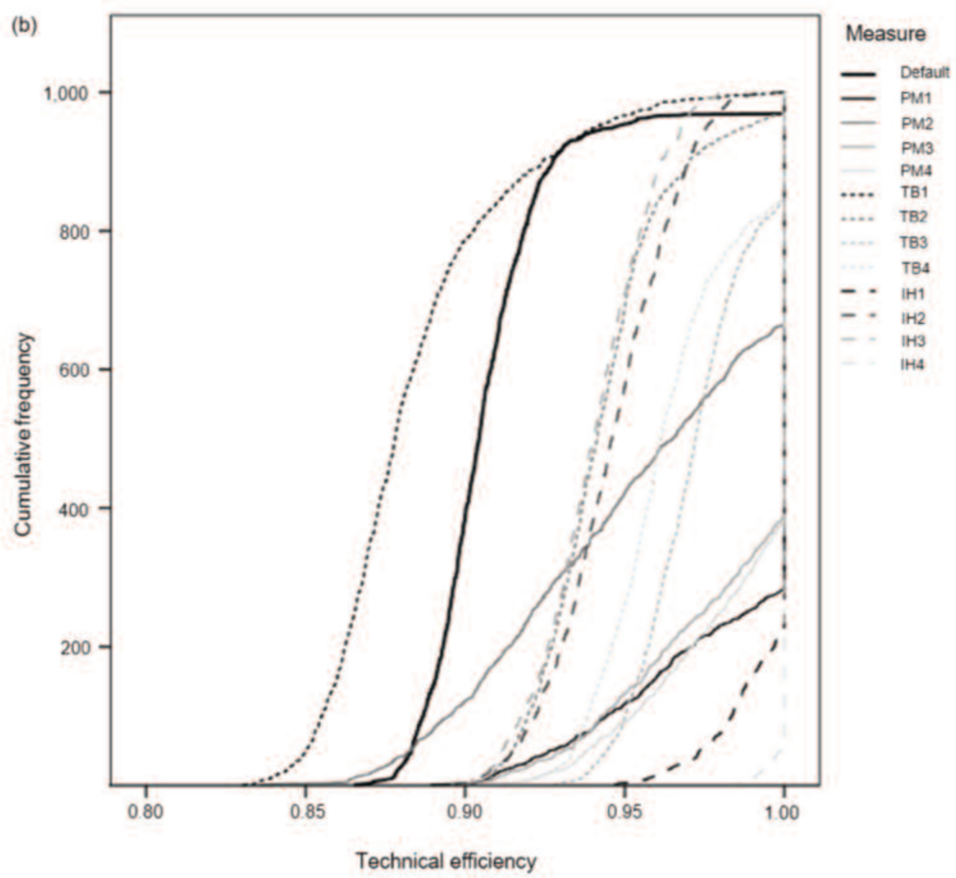
Combined effects of measures

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

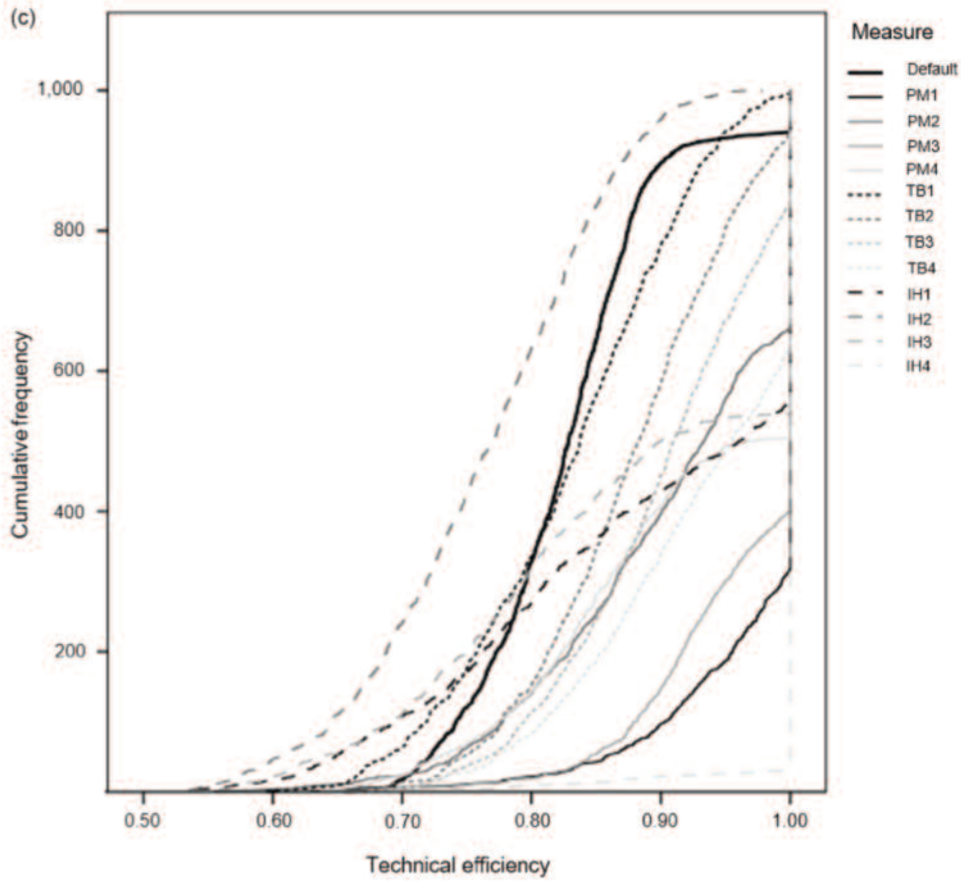
Figure 2





https://doi.org/10.7120/09627286.29.4.433 Published online by Cambridge University Press

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 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 comprehensive 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.

Acknowledgements

We gratefully acknowledge Anita Hoofs and Robert Hoste for their input and the Van de Ven family for providing us with information about their sow farm. We would also like to thank Chris O'Donnell from the University of Queensland for his hospitality and assistance with Data Envelopment Analysis.

References

Aarts H and Te Velde H 2001 Eten, maar niet willen weten. In: Poll N, Sterrenberg L, Bozkurt E and Miedema I (eds) *Hoe oordelen we over de veehouderij?* Rathenau Instituut: Den Haag, The Netherlands. [Title translation: How do we judge livestock production?]

Aarts MNC, te Velde HM and van Woerkum CMJ 2001 *Hoe oordelen we over de veehouderij?* Rathenau Institute: Den Haag, The Netherlands. [Title translation: What do we think of livestock farming?]

Agrovision bv 2012 *Kengetallenspiegel.* http://www.agrovision.nl

Andersen IL, Berg S and Bøe KE 2005 Crushing of piglets by the mother sow (*Sus scrofa*) - purely accidental or a poor mother? *Applied Animal Behaviour Science 93*: 229-243. https://doi.org/10.1016/j.applanim.2004.11.015

Barnett JL, Hemsworth PH, Cronin GM, Jongman EC and Hutson GD 2001 A review of the welfare issues for sows and piglets in relation to housing. *Australian Journal of Agricultural Research 52*: 1-28. https://doi.org/10.1071/AR00057

Beattie VE, O'Connell NE and Moss BW 2000 Influence of environmental enrichment on the behaviour, performance and meat quality of domestic pigs. *Livestock Production Science 65*: 71-79. https://doi.org/10.1016/S0301-6226(99)00179-7

Beekman V, Bracke M, van Gaasbeek T and van der Kroon S 2002 *Begint een beter dierenwelzijn bij onszelf? Een verkenning van de mogelijkheden voor verbetering van dierenwelzijn door marktwerking*. Report 7.02.02. Agricultural Economics Research Institute: Den Haag, The Netherlands. [Title translation: Does better animal welfare start with ourselves? An exploration of the possibilities for improving animal welfare through market forces]

Bennett R, Kehlbacher A and Balcombe K 2012 A method for the economic valuation of animal welfare benefits using a single welfare score. *Animal Welfare 21*: 125-130. https://doi.org/10.7120/096272812X13345905674006

Bennett RM 1997 Farm animal welfare and food policy. *Food Policy 22*: 281-288. https://doi.org/10.1016/S0306-9192(97)00019-5

Bergstra TJ, Gremmen B and Stassen EN 2015 Moral values and attitudes toward Dutch sow husbandry. *Journal of Agricultural and Environmental Ethics 28*: 375-401. https://doi.org/10.1007/s10806-015-9539-x

Bergstra TJ, Hogeveen H, Kuiper WE, Oude Lansink AGJM and Stassen EN 2017b Attitudes of Dutch citizens toward sow husbandry with regard to animals, humans, and the environment. *Anthrozoös 30*: 195-211. https://doi.org/10.1080/08927936.2017.1310985

Bergstra TJ, Hogeveen H and Stassen EN 2017a Attitudes of different stakeholders toward pig husbandry: a study to determine conflicting and matching attitudes toward animals, humans and the environment. *Agriculture and Human Values 34*: 393-405. https://doi.org/10.1007/s10460-016-9721-4

Blokhuis HJ 2008 International cooperation in animal welfare: the Welfare Quality® project. *Acta Veterinaria Scandinavica 50*: S10. https://doi.org/10.1186/1751-0147-50-S1-S10

Bock BB, van Huik MM, Prutzer M, Kling Eveillard F and Dockes A 2007 Farmers' relationship with different animals: The importance of getting close to the animals. Case studies of French, Swedish and Dutch cattle, pig and poultry farmers. *International Journal of Sociology of Agriculture and Food 15*: 108-125

Boerderij 2018 *Vrijloopkraamhok volop in ontwikkeling.* https://www.boerderij.nl/Varkenshouderij/Achtergrond/2018/5/Vrijloopkraamhok-volop-in-ontwikkeling-279156E/. [Title translation: Free farrowing system in full development]

Boivin X, Lensink J, Tallet C and Veissier I 2003 Stockmanship and farm animal welfare. *Animal Welfare 12*: 479-492

Boogaard BK, Bock BB, Oosting SJ, Wiskerke JSC and van de Zijpp AJ 2011a Social acceptance of dairy farming: the ambivalence between the two faces of modernity. *Journal of Agricultural and Environmental Ethics 24*: 259-282. https://doi.org/10.1007/s10806-010-9256-4

Boogaard BK, Boekhorst LJS, Oosting SJ and Sørensen JT 2011b Socio-cultural sustainability of pig production: Citizen perceptions in the Netherlands and Denmark. *Livestock Science* 140(1-3): 189-200. https://doi.org/10.1016/j.livsci.2011.03.028

Boogaard BK, Oosting SJ and Bock BB 2006 Elements of societal perception of farm animal welfare: A quantitative study in The Netherlands. *Livestock Science 104*: 13-22. https://doi.org/10.1016/j.livsci.2006.02.010

Bornett HLI, Guy JH and Cain PJ 2002 Impact of animal welfare on costs and viability of pig production in the UK. *Journal of Agricultural and Environmental Ethics 16*: 163-186. https://doi.org/10.1023/A:1022994131594

Botreau R, Veissier I, Butterworth A, Bracke MBM and Keeling LJ 2007 Definition of criteria for overall assessment of animal welfare. *Animal Welfare 16*: 225-228

Bracke MBM, de Greef KH and Hopster H 2005 Qualitative stakeholder analysis for the development of sustainable monitoring systems for farm animal welfare. *Journal of Agricultural and Environmental Ethics 18*: 27-56. https://doi.org/10.1007/s10806-004-3085-2

Bracke MBM, Zonderland JJ and Bleumer EJB 2007 Expert judgement on enrichment materials for pigs validates preliminary RICHPIG model. *Applied Animal Behavioural Science 104*: 1-13. https://doi.org/10.1016/j.applanim.2006.05.005

https://doi.org/10.7120/09627286.29.4.433 Published online by Cambridge University Press

Bracke MBM, Zonderland JJ, Lensekens P, Schouten WGP, Vermeer H, Spoolder HAM, Hendriks HJM and Hopster H 1998 Formalised review of environmental enrichment for pigs in relation to political decision making. *Applied Animal Behavioural Science 98*: 165-182. https://doi.org/10.1016/j.applanim.2005.08.021

Bruijnis MRN, Hogeveen H and Stassen EN 2013 Measures to improve dairy cow foot health: consequences for farmer income and dairy cow welfare. *Animal 7*: 167-175. https://doi.org/10.1017/S1751731112001383

Cain PJ and Guy JH 2006 Counting the cost of improved welfare for breeding sows in the UK. *Journal of Farm Management 12*: 427-442

Carlsson F, Frykblom P and Lagerkvist C 2004 Consumer willingness to pay for farm animal welfare - transportation of farm animals to slaughter versus the use of mobile abattoirs. *European Review of Agricultural Economics 34(3)*: 321-344. https://doi.org/10.1093/erae/jbm025

Chrispeels MJ and Mandoli DF 2003 Agricultural ethics. *Plant Physiology 132*: 4-9. https://doi.org/10.1104/pp.103.021881

Cohen NE, Brom FWA and Stassen EN 2009 Fundamental moral attitudes to animals and their role in judgment: An empirical model to describe fundamental moral attitudes to animals and their role in judgment on the culling of healthy animals during an animal disease epidemic. *Journal of Agricultural and Environmental Ethics 22*: 341-359. https://doi.org/10.1007/s10806-009-9157-6

Cromwell GL 2002 Why and how antibiotics are used in swine production. *Animal Biotechnology 13*: 7-27. https://doi.org/10.1081/ABIO-120005767

de Greef K and Casabianca F 2009 The Dutch pork chain: a commodity system resisting threats from the market and society. *Agriculture 38*: 167-174. https://doi.org/10.5367/000000009788632395

de Greef K, Stafleu F and de Lauwere C 2006 A simple value-distinction approach aids transparency in farm animal welfare debate. *Journal of Agricultural and Environmental Ethics 19*: 57-66. https://doi.org/10.1007/s10806-005-4527-1

de Greef KH, Vermeer HM, Houwers HWJ and Bos AP 2011 Proof of principle of the comfort class concept in pigs: Experimenting in the midst of a stakeholder process on pig welfare. *Livestock Science 139*: 172-185. https://doi.org/10.1016/j.livsci.2011.03.005

Den Ouden M, Nijsing JT, Dijkhuizen AA and Huirne RBM 1997 Economic optimization of pork production-marketing chains: I. Model input on animal welfare and costs. *Livestock Production Science 48*: 23-37. https://doi.org/10.1016/S0301-6226(96)01411-X

Dyck GW and Swierstra EE 1987 Causes of piglet death from birth to weaning. *Journal of Animal Science 67*: 543-547. https://doi.org/10.4141/cjas87-053

Edwards SA 2005 Product quality attributes associated with outdoor pig production. *Livestock Production Science 94*: 5-14. https://doi.org/10.1016/j.livprodsci.2004.11.028

Eurobarometer 2016 *Attitudes of Europeans towards animal welfare. Special Eurobarometer 442, November–December 2015*. European Union: Brussels, Belgium. https://ec.europa.eu/commfrontoffice/publicopinion/index.cfm/Survey/getSurveyDetail/search/animal/surveyKy/2096

Fraser D 1999 Animal ethics and animal welfare science: bridging the two cultures. *Applied Animal Behaviour Science 65*: 171-189. https://doi.org/10.1016/S0168-1591(99)00090-8

Fraser D 2003 Assessing animal welfare at the farm and group level: The interplay of science and values. *Animal Welfare 12*: 433-443

Frederiksen B, Johnsen AMS and Skuterud E 2010 Consumer attitudes towards castration of piglets and alternatives to surgical castration. *Research in Veterinary Science 90*: 352-357. https://doi.org/10.1016/j.rvsc.2010.06.018

Galama PJ, de Vries C and van Dooren HJC 2009 *Grensverleggend huisvesten van melkvee. Report 271*. Wageningen UR Livestock Research: Zoetermeer, The Netherlands. [Title translation: Groundbreaking housing of dairy cattle]

Glass GA, Hutchinson WG and Beattie VE 2005 Measuring the value to the public of pig welfare improvements: a contingent valuation approach. *Animal Welfare 14*: 61-69

Gocsik É, Oude Lansink AGJM and Saatkamp HW 2013 Mid-term financial impact of animal welfare improvements in Dutch broiler production. *Poultry Science 92*: 3314-3329. https://doi.org/10.3382/ps.2013-03221

Harper G and Henson S 2001 *Consumer concerns about animal welfare and the impact on food choice. EU FAIR CT98-3678*. Centre for Food Economics Research (CeFER): UK

Hemsworth PH, Barnett JL and Coleman GJ 1993 The human-animal relationship in agriculture and its consequences for the animal. *Animal Welfare 2*: 33-51

Herskin MS, Jensen KH and Thodberg K 1998 Influence of environmental stimuli on maternal behaviour related to bonding, reactivity and crushing of piglets in domestic sows. *Applied Animal Behaviour Science 58*: 241-254. https://doi.org/10.1016/S0168-1591(97)00144-5

Holyoake PK, Dial GD, Trigg T and King VL 1995 Reducing pig mortality through supervision during the perinatal period. *Journal of Animal Science 73*: 3543-3551. https://doi.org/10.2527/1995.73123543x

Hoofs AIJ 2012 *Pro Dromi Easy Nesting Geeft Rust en Minder Doodliggers* pp 18-19. Agri Media: Wageningen, The Netherlands. [Title translation: Pro Dromi Easy Nesting provides peace and fewer sleepers]

Huber-Eicher B and Spring P 2008 Attitudes of Swiss consumers towards meat from entire or immunocastrated boars: A representative survey. *Research in Veterinary Science 85*: 625-627. https://doi.org/10.1016/j.rvsc.2008.03.002

Hudson D 2010 Discussion: The economics of animal welfare. *Journal of Agricultural and Applied Economics 42*: 453-455. https://doi.org/10.1017/S1074070800003631

Huijps K, Hogeveen H, Lam TJGM and Oude Lansink AGJM 2010 Costs and efficacy of management measures to improve udder health on Dutch dairy farms. *Journal of Dairy Science 93*: 115-124. https://doi.org/10.3168/jds.2009-2412

Hunter EJ, Jones TA, Guise HJ, Penny RHC and Hoste S 2001 The relationship between tail biting in pigs, docking procedure and other management practices. *The Veterinary Journal 161*: 72-79. https://doi.org/10.1053/tvjl.2000.0520

Huysman CN, Roelofs PFMM, Plagge JG and Hoofs AIJ 1994 *Motherless rearing or extention of the suckling period of piglets using 'EMMA.'* https://edepot.wur.nl/35501

Ingenbleek PTM, Immink VM, Spoolder HAM, Bokma MH and Keeling LJ 2012 EU animal welfare policy: Developing a comprehensive policy framework. *Food Policy 37*: 690-699. https://doi.org/10.1016/j.foodpol.2012.07.001

Kanis E, Groen ABF and de Greef KH 2003 Societal concerns about pork and pork production and their relationships to the production system. *Journal of Agricultural and Environmental Ethics 16*: 137-162. https://doi.org/10.1023/A:1022985913847

Kehlbacher A, Bennett R and Balcombe K 2012 Measuring the consumer benefits of improving farm animal welfare to inform welfare labelling. *Food Policy 37*: 627-633. https://doi.org/10.1016/j.foodpol.2012.07.002

Knight S and Barnett L 2008 Justifying attitudes toward animal use: A qualitative study of people's views and beliefs. *Anthrozoös 21*: 31-42. https://doi.org/10.2752/089279308X274047

Knight S, Vrij A, Cherryman J and Nunkoosing K 2004 Attitudes towards animal use and belief in animal mind. *Anthrozoös 17*: 43-62. https://doi.org/10.2752/089279304786991945

Korthals M 2001 Taking consumers seriously: two concepts of consumer sovereignty. *Journal of Agricultural and Environmental Ethics 14(2)*: 201-215. https://doi.org/10.1023/A:1011356930245

KWIN-Veehouderij 2013/2014 *Handboek Kwantitatieve Informatie Veehouderij*. Wageningen UR Livestock Research: Lelystad, The Netherlands. [Title translation: Handbook of Quantitative Information on Livestock]

Lagerkvist CJ and Hess S 2011 A meta-analysis of consumer willingness to pay for farm animal welfare. *European Review of Agricultural Economics 38*: 55-78. https://doi.org/10.1093/erae/jbq043

Lassen J, Sandøe P and Forkman J 2006 Happy pigs are dirty! Conflicting perspectives on animal welfare. *Livestock Science 103*: 221-230. https://doi.org/10.1016/j.livsci.2006.05.008

Loncke R, Dewulf J, Vanderhaeghe C, de Kruif A and Maes D 2009 Non-infectious causes of piglet mortality before weaning Part 2: Factors related to the sow and the environment. *Vlaams Diergeneeskdig Tijdschrift 78*: 71-81

LTO Nederland 2005-2006 *Ruimte om te ondernemen, maatschappelijk verslag varkenshouderij*. LTO Nederland: Den Haag, The Netherlands. [Title translation: Space to do business, sustainability report pig husbandry]

Marchant JN, Broom DM and Coming S 2001 The influence of sow behaviour on piglet mortality due to crushing in an open farrowing system. *Animal Science 72*: 19-28. https://doi.org/10.1017/S135772980005551X

Martić MM, Novaković MS and Baggia A 2009 Data envelopment analysis - Basic models and their utilization. *Organizacija 42*: 37-43. https://doi.org/10.2478/v10051-009-0001-6

McGlone JJ 2001 Farm animal welfare in the context of other society issues: toward sustainable systems. *Livestock Production Science 72*: 75-81. https://doi.org/10.1016/S0301-6226(01)00268-8

Mellor DJ and Stafford KJ 2001 Integrating practical, regulatory and ethical strategies for enhancing farm animal welfare. *Australian Veterinary Journal 79*: 762-768. https://doi.org/10.1111/j.1751-0813.2001.tb10895.x

Meuwissen MPM and van der Lans IA 2005 Trade-offs between consumer concerns: An application pork supply chains. *Food Economics - Acta Agriculturae Scandinavica, Section C2*: 27-34. https://doi.org/10.1080/16507540510033442

Moinard C, Mendl M, Nicol CJ and Green LE 2003 A case control study of on-farm risk factors for tail biting in pigs. *Applied Animal Behaviour Science 81*: 333-355. https://doi.org/10.1016/S0168-1591(02)00276-9

Ngapo TM, Dransfield E, Martin JF, Magnusson M, Bredahl L and Nute GR 2003 Consumer perceptions: pork and pig production. Insights from France, England, Sweden and Denmark. *Meat Science 66*: 125-134. https://doi.org/10.1016/S0309-1740(03)00076-7

Nocella G, Hubbard L and Scarpa R 2010 Farm animal welfare, consumers willingness to pay, and trust: results of a cross-national survey. *Applied Economic Perspectives and Policy 32*: 275-297. https://doi.org/10.1093/aepp/ppp009

Pedersen LJ, Damm BI, Marchant-Forde NJ and Jensen KH 2003 Effects of feed-back from the nest on maternal responsiveness and postural changes in primiparous sows during the first 24 h after farrowing onset. *Applied Animal Behaviour Science 83*: 109-124. https://doi.org/10.1016/S0168-1591(03)00116-3

Rokeach M 1968-1969 The role of values in public opinion research. *Public Opinion Quarterly 32*: 547-559. https://doi.org/10.1086/267645

Rooke JA and Bland IM 2002 The acquisition of passive immunity in the new-born piglet. *Livestock Production Science 78*: 13-23. https://doi.org/10.1016/S0301-6226(02)00182-3

Rutseart P, Pieniak Z, Regan Á, McConnon Á, Kuttschreuter M, Lores M, Lozano N, Guzzon A, Santare D and Verbeke W 2014 Social media as a useful tool in food risk and benefit communication? A strategic orientation approach. *Food Policy 46*: 84-93. https://doi.org/10.1016/j.foodpol.2014.02.003

Seddon YM, Cain PJ, Guy JH and Edwards SA 2013 Development of a spreadsheet based financial model for pig producers considering high welfare farrowing systems. *Livestock Science 157*: 317-321. https://doi.org/10.1016/j.livsci.2013.07.003

Stichting Varkens in Nood 2010 *In de media*. http://www.varkensinnood.nl. [Title translation: In the media]

Stott AW, Vosough Ahmadi B, Dwyer CM, Kupiec B, Morgan-Davies C, Milne CE, Ringrose S, Goddard P, Phillips K and Waterhouse A 2012 Interactions between profit and welfare on extensive sheep farms. *Animal Welfare 21*: 57-64. https://doi.org/10.7120/096272812X13345905673683

Svedalis N and Harvey N 2006 Determinants of willingness to pay in separate and joint evaluations of options: Context matters. *Journal of Economic Psychology 27*: 377-385. https://doi.org/10.1016/j.joep.2005.07.001

Swindle MM 2008 Anesthesia and analgesia in swine. *Sinclair Research Technical Bulletin: 1-7*. https://sinclairresearch.com/whitepapers/anesthesia-and-analgesia-in-swine/

Te Velde H, Aarts N and van Woerkum C 2002 Dealing with ambivalence: Farmers' and consumers' perceptions of animal welfare in livestock breeding. *Journal of Agricultural and Environmental Ethics 15*: 203-219. https://doi.org/10.1023/A:1015012403331

Tuyttens FAM 2005 The importance of straw for pig and cattle welfare: A review. *Applied Animal Behavioural Science 92*: 261-282. https://doi.org/10.1016/j.applanim.2005.05.007

Tuyttens FAM, Vanhonacker F, van Poucke E and Verbeke W 2010 Quantitative verification of the correspondence between the welfare quality operational definition of farm animal welfare and the opinion of Flemish farmers, citizens and vegetarians. *Livestock Science 131*: 108-114. https://doi.org/10.1016/j.livsci.2010.03.008

Vair 2014 *Vair varkenshuis*. http://www.vair.nl/vair-varkenshuis/. [Title translation: Vair pig house]

Van den Besselaar P and Heimeriks G 2001 Disciplinary, multidisciplinary, interdisciplinary: Concepts and indicators. *Paper for the 8th conference on Scientometrics and Informetrics* pp 705-716. 16-20 July 2001, Sydney, Australia

Van der Meulen HAB, de Bont CJAM, Agricola HJ, van Horne PLM, Hoste R, van der Knijff A, Leenstra FR, van der Meer RW and de Smet A 2011 *Schaalvergroting in de land - en tuinbouw. Rapport 2010-094.* Agricultural Economics Research Institute: Wageningen, The Netherlands. [Title translation: Upscaling in agriculture and horticulture]

Van der Peet-Schwering CMC, Hoofs AIJ, Vermeer HM and Binnendijk GP 2010 *Groepshuisvesting voor drachtige zeugen: kenmerken van de verschillende systemen*. Wageningen UR Livestock Research: Wageningen, The Netherlands. [Title translation: Group housing for pregnant sows: characteristics of the different systems]

Vanhonacker F, Verbeke W, van Poucke E and Tuyttens FAM 2007 Segmentation based on consumers' perceived importance and attitude toward farm animal welfare. *International Journal of Sociology of Food and Agriculture 15(3)*: 84-100

Vanhonacker F, Verbeke W, van Poucke E and Tuyttens FAM 2008 Do citizens and farmers interpret the concept of farm animal welfare differently. *Livestock Science 116*: 126-136. https://doi.org/10.1016/j.livsci.2007.09.017

Van Huik MM and Bock BB 2007 Attitudes of Dutch pig farmers towards animal welfare. *British Food Journal 11*: 879-890. https://doi.org/10.1108/00070700710835697

Van Niekerk T and Reuvekamp B 2011 Rondeel™ , a new housing design for laying hens. *Lohmann Information 46*: 25-31

Verbeke W 2009 Stakeholder, citizen and consumer interests in farm animal welfare. *Animal Welfare 18*: 325-333

Verbeke WAJ and Viaene J 2000 Ethical challanges for livestock production: meeting consumer concerns about meat safety and animal welfare. *Journal of Agricultural and Environmental Ethics 12*: 141-151. https://doi.org/10.1023/A:1009538613588

Vermeer M, Van Reenen CG and Spoolder HAM 2012 *Vereenvoudiging Welfare Quality® protocol voor varkens. Report 622*. Wageningen UR Livestock Research: Lelystad, The Netherlands. [Title translation: Simplification Welfare Quality® protocol for pigs]

Vosough Ahmadi B, Stott AW, Baxter EM, Lawrence AB and Edwards SA 2011 Animal welfare and economic optimisation of farrowing systems. *Animal Welfare 20*: 57-67

Wakker dier 2010 *Persberichten*. http://www.wakkerdier.nl. [Title translation: Press release]

Welfare Quality® 2009 *Welfare Quality® assessment protocol for pigs (sows and piglets, growing and finishing pigs)*. Welfare Quality® Consortium: Lelystad, The Netherlands

Winkel A and Bokma S 2011 *Adviezen voor daglicht in varkensstallen* pp 36-37. Agri Media: Wageningen, The Netherlands. [Title translation: Advice for daylight in pig stables]

Yang TS, Howard B and Macfarlane WV 1981 Effects of food on drinking behaviour of growing pigs. *Applied Animal Ethology 7*: 259-270. https://doi.org/10.1016/0304-3762(81)90082-1

Zonderland JJ 2007 *Afleidingsmateriaal voor varkens breed gewogen*. Animal Science Group: Wageningen University, Lelystad, The Netherlands. [Title translation: Practical aspects of environmental enrichment]

Zonderland JJ, Cornelissen L, Wolthuis-Fillerup M and Spoolder HAM 2008a Visual acuity of pigs at different light intensities. *Applied Animal Behavioural Science 111(1-2)*: 28-37. https://doi.org/10.1016/j.applanim.2007.05.010

Zonderland JJ, Wolthuis-Fillerup MM, van Reenen CG, Bracke MBM, Kemp LA, den Hartog and Spoolder HAM 2008b Prevention and treatment of tail biting in weaned piglets. *Applied Animal Behavioural Science 110*: 269-281. https://doi.org/10.1016/j.applanim.2007.04.005