Animal Welfare 2022, 31: 361-371
ISSN 0962-7286
doi: 10.7120/09627286.31.4.004

A formal model for assessing the economic impact of animal welfare improvements at bovine and porcine slaughter

*J Jerlström**†, C Berg†, AH Karlsson†, A Wallenbeck† and H Hansson‡*

† Department of Animal Environment and Health, Faculty of Veterinary Medicine and Animal Sciences, Swedish University of Agricultural Sciences (SLU), Box 234, 532 23 Skara, Sweden
‡ Department of Economics, Faculty of Natural Resources and Agricultural Sciences, Swedish University of Agricultural Sciences (SLU), Box 7013, 750 07 Uppsala, Sweden
* Contact for correspondence: josefine.jerlstrom@slu.se

Abstract

The relationship between animal welfare at slaughter and slaughterhouse profitability is complex, with potential trade-offs between animal welfare costs and benefits. Slaughterhouses currently lack data support for decisions on investments that can improve both animal welfare and profitability. Therefore, this study mapped the economic impacts for slaughterhouse businesses of improved cattle and pig welfare at slaughter. Specific aims were to: (i) highlight the possible economic impact of animal welfare improvements, based on the scientific literature; (ii) develop an economic model demonstrating the theoretical contribution of animal welfare to slaughterhouse profitability; and (iii) validate the economic model through focus group interviews with slaughterhouse personnel in Sweden. The findings indicated that investing in animal welfare improvements could result in accumulation of an intangible asset that can be considered together with other production factors in the economic model. Model validation stressed the importance of selling by-products for the economic outcome and of smooth workflow for productivity. The study thus improves understanding of the economic impacts of animal welfare at slaughter and incentives for slaughterhouse businesses to improve animal welfare. The results are important for public and private policy-makers interested in enhancing animal welfare at slaughter.

Keywords: *abattoir, animal welfare, cattle, economic impact, pigs, profitability*

Introduction

There is considerable public interest in the welfare of farm animals in general and in the handling of animals at slaughterhouses in particular (Fernandes *et al* 2021). Therefore, many food chain actors (including slaughterhouse workers) are striving to improve the welfare of farm animals. Since consumption of beef and pork worldwide is expected to increase with a growing and increasingly wealthy global population, it is highly relevant to ensure acceptable welfare standards for animals produced for meat (Alexandratos & Bruinsma 2012). Animal welfare is defined by Fraser *et al* (1997) as the subjective experience of the animal and its biological functioning and adaptation to its current environment, and it includes all parts of an animal's life. Improving animal welfare means ensuring good living conditions for farm animals during their life and at slaughterhouse level, with the latter often requiring alterations to infrastructure such as avoiding slippery flooring or high-pitched motor noises (Grandin 2000), or training personnel in animal welfare-friendly stunning methods (Leary *et al* 2013). There is a considerable body of literature about the links between pre-slaughter stress, animal handling and meat quality (Costa *et al* 2006; Chulayo & Muchenje 2015), but the economic consequences for slaughterhouses of impaired welfare practices pre-slaughter are less well explored.

The relationship between animal welfare at slaughter and production costs is complex, with some costs being obvious and others challenging to evaluate using econometric methods. There is concern that increased animal welfare could be linked to higher production costs, leading to impaired competitiveness at farm and slaughterhouse level. Recent studies have considered the relationship between animal welfare and economic outcomes at farm level, focusing on pig production (Alvåsen *et al* 2017; Henningsen *et al* 2018) and beef fattening operations (Ahmed *et al* 2020). Other studies have indicated, but not verified, interactions between animal welfare at slaughter and slaughterhouse profitability (McInerney 2004; Gibson & Jackson 2017). At the same time, there is an ongoing debate about animal welfare at slaughter and the potential trade-offs between costs and benefits (Fernandes *et al* 2021). It is important for the slaughter sector to understand the economic consequences of improved animal welfare since it can aid their decision-making. However, there is a

lack of understanding about the relationship between animal welfare improvements and economic outcomes of cattle and pig slaughterhouse operations. This is problematic for slaughterhouses, which do not have sufficient data support for decisions about investments in animal welfare that can enhance both animal welfare and profitability. It is also problematic from a societal perspective, as policy-makers do not know whether slaughterhouses have sufficient economic incentive to invest in animal welfare.

Several studies have reported high consumer awareness and willingness to pay for farm animal welfare product quality attributes (Lagerkvist & Hess 2011; Leonardsson *et al* 2011). Napolitano *et al* (2008) found that providing information about animal welfare to consumers could have a major impact on their willingness to pay for animal-based food products. Moreover, animal-friendly products are considered by consumers to be of higher quality, healthier, more hygienic and safer (Alonso *et al* 2020). On the other hand, consumers seem to have low interest in receiving information about the slaughter procedure, which could be due to personal doubts towards the killing of animals for food (Gori *et al* 2017). Slaughterhouse businesses could benefit from listening to consumer demands and differentiate meat products, which would increase their competitiveness and improve animal welfare.

The overall aim of this study was to map the economic impacts for slaughterhouse businesses of improving the welfare of cattle and pigs at slaughter. Specific aims were to: (i) highlight the possible economic impact of animal welfare improvements, using a review of the scientific literature; (ii) develop an economic model to show the contribution of animal welfare to slaughterhouse profitability from a theoretical perspective; and (iii) validate the economic model through focus group interviews with slaughterhouse personnel in Sweden. This paper makes several novel contributions to the literature. It describes the first attempt to develop an economic model for slaughterhouses in relation to animal welfare and highlights how animal welfare enters the production function in slaughterhouses. The model can be used to relate proposed animal welfare improvements at slaughter to the economic outcome for the slaughterhouse business. The paper also improves understanding of the economic incentives for slaughterhouse businesses to improve animal welfare. The results can be used as a starting point for discussions on how investments in animal welfare improvements can be internalised in strategic decision-making by slaughterhouse businesses.

This paper starts with presenting a review of the relevant literature in the field of animal welfare at slaughter. It continues with a research approach where the methodology for developing the economic model and of the focus group interviews are described. In *Results*, the economic model together with the validation of the model and the identified themes from the focus group interviews are presented. The *Discussion* includes an analysis of the economic model and the potential economic effects of animal welfare improvements. Thereafter, *Animal welfare implications and conclusion* can be seen.

Literature review

Economic effects of animal welfare at slaughter

Since Lusk (2011) first identified a significant gap in the production economics literature concerning animal welfare, there are to our knowledge still no published studies on the relationship between animal welfare at slaughter and the economic outcome for the slaughterhouse business. Knowledge of how animal welfare improvements might affect the economic status of slaughterhouse businesses is important in identifying their economic incentives for improving animal welfare. This was shown by Lusk (2011), who proposed a scheme to quantify and trade units of farm animal welfare, due to the current lack of market incentives. The benefits of improving farm animal welfare (FAW), and animal welfare at slaughter, are difficult to evaluate from a purely economic perspective, since they take the form of intangible gains in productivity or competitive advantage and market premiums (Hemsworth *et al* 2002; Fernandes *et al* 2021). Production economics research can help reveal the economic incentives of slaughterhouses for improving or reducing animal welfare.

A study by Alleweldt *et al* (2007) found that poor meat quality can reduce the carcase grade, and thereby the wholesale value of the meat. Other studies have attempted to estimate the cost of animal welfare-related problems in slaughterhouses, such as the prevalence of carcase bruises. Huertas *et al* (2015) examined 15,157 carcases of cattle slaughtered in Uruguay and found that 60% were bruised to some extent, probably due to pre-slaughter handling of the animals, poorly maintained trucks and failures at trailer gate opening. Estimated direct losses of this carcase damage, calculated as the product of the number of bruises and the estimated weight of condemned carcases, divided by the total number of slaughter cattle observed, were 899 g per carcase (Huertas *et al* 2015). Considering the 2.5 million head of cattle slaughtered annually in Uruguay and assuming an average price of $US4 per kg (2012), the overall loss to the national economy due to bruises would be approximately $US8 billion per year. According to Grandin (1995), a one-minute delay in a large-scale slaughterhouse can cost as much as $US100–200. In Canadian slaughterhouses, beef spoilage due to dark cutting (DFD) represents around $US1.13 million in lost carcase value each year (Holdstock *et al* 2014), while in the Australian beef industry the corresponding annual loss is estimated to be $US26.6 million (Wigham *et al* 2018).

Economic effects of animal welfare improvements at slaughter

The literature suggests that animal welfare is a key factor for the economics of slaughterhouse businesses and that treating animals in a humane manner can bring many economic benefits for the industry (Grandin 1995; Gallo & Huertas 2015; Wigham *et al* 2018). Implementing animal welfare improvements could reduce production costs and

https://doi.org/10.7120/09627286.31.4.004 Published online by Cambridge University Press

improve the quality of the output (carcases, meat and by-products). However, the literature does not provide any information on approaches to assess the economic effects of animal welfare improvements on slaughterhouse productivity. Reported effects are instead based upon reasoning and personal experiences (Grandin 1995). However, one important distinction when linking animal welfare to economics is that animal welfare concerns the single, individual animal and whether it experiences negative or positive states of welfare, while economics considers the perspective of society and focuses on factors relating to human demands and preferences (Gibson & Jackson 2017). Possible and feasible animal welfare factors at slaughter and their predicted impact on the economic outcome for the slaughterhouse business, identified from the scientific literature, are summarised in Table S1.

High stress in animals before slaughter impairs meat quality (Warner *et al* 2007), due to meat discards or entire carcase condemnations (downgrading and rejections), and thereby generates direct costs and foregone revenues for the slaughterhouse or the processing industry (Alleweldt *et al* 2007). Carcase defects such as pale soft exudative (PSE) and dark cutting represent an economic loss to the meat distribution chain and are a strong indicator of impaired animal welfare related to high stress levels in the live animal, which could have occurred at the farm, during transport or in the slaughterhouse (Grandin 1997, 2007).

Sub-optimal design of the slaughterhouse interior reduces animal welfare (Hultgren *et al* 2014) and may lead to sub-optimal workflow, which can cause frustration among workers and reduce the flow of animals through the slaughter process (Grandin 1996; Gallo *et al* 2003; Wiberg 2012). This reduces the production efficiency of the slaughterhouse business.

Knowledge and skills levels can be expected to vary considerably between slaughterhouse personnel, depending on, for example, experience and education (Atkinson *et al* 2013). Council Regulation (EC) No 1099/2009 (on the protection of animals at the time of killing), which came into force in the EU on 1 January 2013, requires formal education of all slaughterhouse personnel who handle animals. Prior to that, the amount of theoretical and practical training was possibly unsatisfactory in some slaughterhouses, although national legislation in some countries (including Sweden) already required training of slaughterhouse personnel. Previous studies indicate that there may be an opportunity to improve stockperson actions, and consequently reduce stress in cattle at slaughterhouses, by targeting attitudes with appropriate educational and training material (Breuer *et al* 2000; Coleman *et al* 2012). Improvements in animal welfare can also reduce the amount of labour required for handling and stunning if, for example, the animals move voluntarily through the system (Grandin 1995).

Research approach

Development and validation of the economic model

Our approach to assess the economic impacts of animal welfare at slaughter was based on a previous study that developed a formal economic model for pork production marketing chains, which assumed that slaughterhouses are profit maximisers (Den Ouden *et al* 1997). The economic model was based on a profit function, which describes the slaughterhouses' costs and revenues to find the optimal output level. Furthermore, animal welfare was presented as an intangible asset in the production function.

Structure and procedure of the focus group interviews

We used focus group interviews with slaughterhouse personnel to: (i) identify how the economic outcome in slaughterhouses may be related to animal welfare improvements; and (ii) validate the slaughterhouse-specific details of the model and inclusion of animal welfare in the model.

We conducted two focus group interviews with slaughterhouse staff members with different positions, since we wanted to determine whether they could see a connection between investments in animal welfare improvements and the economic outcome. The first focus group consisted of four female employees working with the quality assurance schemes and animal welfare in their respective slaughterhouse. The second focus group consisted of three male employees (although one could not participate in the whole group interview and was interviewed separately for the remaining parts), working as slaughter managers in their respective slaughterhouse. All seven participants had formal education in animal welfare according to EC 2009/1099. Approximately one week prior to the meeting, the participants received an email with instructions and questions to prepare for the interview. The meetings were arranged over virtual meeting platforms in November 2019 and April 2021, and each focus group interview lasted for three hours. Prior to the interviews respondents were informed about their anonymity and the confidentiality of the interview. They were also informed that they could choose to discontinue the interview at any time and refuse to answer any questions. Ethical approval for this study is not needed according to the Swedish Act 2003: 460 since we do not ask about the type of sensitive personal information that requires this.

The objective of the focus group interviews was to validate the economic model (see Equation 7) and to probe respondents about how different investments in animal welfare improvements might influence the economic outcome for their slaughterhouse. Focus group interviews are a quantitative method of deriving valuable, in-depth data from specific people of interest (Coyne *et al* 2014). The moderator allows the participants to influence the content but steers the discussions to cover a number of predetermined topics. This method facilitates study of values, motivations, attitudes and

behaviours that occurs in social interactions (Carson *et al* 2011; Algers & Berg 2017). Focus group interviews were considered particularly useful for our purposes since the interview format, where respondents can develop their responses based on other respondents' answers, allows them to go deep in their reasoning and uncover aspects they may not have considered initially. This was especially important for the research topic in this study, ie the relationship between investments in animal welfare improvements and the economic outcome for slaughterhouses.

The focus group meetings started with a presentation of the project and information about the current lack of data on the links between economics and animal welfare at slaughter. The focus group interviews then covered three main themes:

• The most important animal welfare factors influencing the economic outcome for the slaughterhouse;

• The economic model and slaughterhouse economics in general, ie the most important costs and revenues; and

• Previous and planned investments in animal welfare improvements at the slaughterhouse.

The focus group interviews were led by two female facilitators (JJ and HH) who had competence within animal science and animal welfare aspects of slaughter (JJ) and within agriculture economics at professor level and with substantial experience in research based on interviews (HH). One facilitator took notes and the other moderated the meeting. When necessary, both facilitators asked questions and took notes. The notes from the interviews were anonymised, summarised and subjected to thematic analysis to determine certain themes or concepts across the qualitative data (Braun & Clarke 2006).

Results

Developing an economic model for slaughterhouses

The slaughterhouse business normally purchases animals directly from farmers and either sells the products under its own brand or sells the carcase to retailers for further processing. Another option in Sweden is sub-contract slaughter, where farmers send their animals to the slaughterhouse for slaughter, processing and packaging and then sell the meat directly to consumers. This is a specific situation for northern Europe while in other countries the slaughterhouses provide these services. We based our economic model on the first option, ie where the slaughterhouse purchases the animals from the farmer. The animal then passes through the slaughter chain, comprising transport, slaughter, processing, manufacturing, distribution, portioning, packaging and finally retail sale. Based on the demand for beef or pork products, carcases are assigned to various processing options, thus determining the processing costs and the carcase value. This formal economic model for slaughterhouses handling cattle and/or pigs highlight how animal welfare can be considered at a conceptual level to affect the production process in slaughterhouses.

Any profit-maximising firm, including a slaughterhouse, can find its optimal output level by considering the point at which profits are maximised. At its most general level, the profit function of the slaughterhouse can be described as:

$$\pi(q) = R(q) - C(q) \quad (1)$$

where $\pi(q)$ is the profit of the slaughterhouse, $R(q)$ is the revenue function, $C(q)$ the cost function and q is the number of units produced and sold; and both revenues and costs depend on output. It is assumed that all products produced are sold. The optimal output is found by maximising the profit function (1).

In the case of slaughterhouses, revenues depend on both the carcases (*q1*) and the by-products (*q2*), ie hides, organs, bones and other parts of the animals produced as a consequence of production of meat carcases. The revenue from carcases mainly depends on the carcase classification and the price (SEK per kg cold carcase weight). All carcases produced in Sweden and intended for sale on the open market must be classified according to a set of Swedish Board of Agriculture and EU regulations (similar systems apply in other EU member states). Carcases of cattle are assessed according to the EUROP carcase classification system, which includes category (eg cow, heifer, bull), carcase shape and carcase fat composition. Carcases of pigs are assessed by category (eg slaughter pig, sow, boar) and carcase leanness (meat content percentage) according to the Hennessy Grading System (HGS), where the difference in reflectance between muscle and fat is measured by a probe in the *M. longissimus dorsi*. The carcase price group (SEK per kg cold carcase weight) is dependent on the classification result and carcase weight. Production of by-products (*q2*) is driven by the variable *q1*, and revenue is generated by the price (*p1*) of *q1* and the price (*p2*) of *q2*. The slaughterhouse revenue function can then be described as:

$$R(q1) = p1 \times q1 + p2 \times q2 \text{ where } q2 = f(q1) \quad (2)$$

The process of transforming production factors into outputs can be described from the production function, which specifies how production factors such as capital services (K), labour services (L), material services (M) and energy services (E) produce q:

$$q = f(K, L, M, E) \quad (3)$$

where q units of output are the maximum level of production that can occur when using K units of capital services, L units of labour services, M units of material and E units of energy services.

For a slaughterhouse, the capital is long-term inputs such as buildings (capital); the labour is supplied by managers and employees (hours); the material is the live animals bought from the farmer (kg cold carcase weight); and the energy is electricity (Kwh) and water (litres).

The total production costs (TC) of the slaughterhouse can be described by the fixed (FC) and variable costs (VC), depending on the number of units produced. The slaughterhouse costs include wages, cost of capital and cost of other production factors. The slaughterhouse cost function can be described as:

$$C(q1) = FC + VC(q1) \quad (4)$$

https://doi.org/10.7120/09627286.31.4.004 Published online by Cambridge University Press

To illustrate how animal welfare may affect the production process, animal welfare (*AW*) describes the input needed in the slaughter production system and decisions that can be made in detecting desired animal welfare objectives. In particular, through investments in specific animal welfare practices, it can be considered that the overall *AW* in the slaughterhouse increases. Based on the literature available, we identified a list of factors (Table S1) that can be assumed to have an impact on costs, revenues and *AW*, and thus on the economic output of the slaughterhouse. As a proxy, we considered accumulated investment in animal welfare in the slaughterhouse and handled it as an intangible asset that functions as a production factor. This is because investing in animal welfare improvements is assumed to lead to an increase in slaughterhouse output:

$$q = f(K, L, M, E, AW) \quad (5)$$

Production thus takes place with the production factors specified by the components indicated by the fixed and variable costs:

$$C(q1) = FC + VC(q1) \quad (6)$$

where $FC = Pk \times \acute{K}$ and k is fixed in the short term.

In the short term, the slaughterhouse has limited possibilities to change its use of production factors. It can relatively rapidly change the amount of labour needed to perform the activities but building a new housing facility is not possible in the short term. Therefore, $\acute{K}$ is the fixed number of units in the cost function and *Pk* is the cost of capital. Other costs, eg wages, vary proportionally with the scale of operation.

Taking the costs and revenues into account, the profit function of the slaughterhouse will be:

$$\pi(q1) = (p1 \times q1 + p2 \times q2) - (FC + VC[q1]) \quad (7)$$

where:

$$q1 = f(K, L, M, E, AW)$$

$$q2 = f(q1)$$

and $FC = Pk \times \acute{K}$ and k is fixed in the short term.

Validation of the economic model based on the slaughterhouses' investments in animal welfare improvements

To validate the economic model and the impact of animal welfare on the economic outcome for slaughterhouses, the respondents of the focus group interviews were asked to specify and discuss the costs and revenues, and where these stem from. The largest amount of money is obtained from selling the carcases but, interestingly, the respondents pointed out the importance of profitable by-products. Apparently, at least in some slaughterhouses, profit is obtained in particular by selling high-margin by-products. Therefore, the respondents stressed the importance of finding a market for the whole animal, including searching for new areas for by-products. Some examples of by-products include selling marrowbones for stock production, offal for production of dog food and export of, eg rumen to Asian markets and lower legs from cows and pigs to African markets. Earlier, when Sweden's hide industry was more well-developed, the slaughterhouses received higher returns from selling hides, but today the income from that source is low. Furthermore, the slaughterhouses send non-saleable by-products from the slaughter line (production waste) to biogas production. Some of the participating slaughterhouses had invested in their own biogas facility, which they expected to generate higher revenue than selling it to an external biogas company due to the high waste transportation costs. Several respondents were of the opinion that subcontract slaughter is an important service that generates considerable revenue.

The respondents specified and discussed fixed and variable costs of slaughterhouses. Fixed costs mentioned were labour (capacity building of employees), capital, inspection fees to authorities and certification companies (eg the National Food Agency or organic production auditors) and environmental work (eg laboratory samples and fees to laboratories). The variable costs referred to were material (ie consumer goods, knives, ammunition, special equipment and technology), energy (ie electricity, water, sewage water handling and treatment), and transport of animals from farm to slaughterhouse, meat to retailers, waste and by-products from the carcase, waste and specified risk material (SRM). The respondents emphasised that having the right number of slaughterhouse personnel in relation to the design and slaughter capacity was the most effective measure to influence fixed costs.

The respondents reported that their respective slaughterhouse had already invested, or is planning to invest, in animal welfare improvements (Table S2). The improvements mentioned were re-design of slaughterhouse interiors and improving the efficiency of the slaughter line. The respondents reported that this has led to a more efficient slaughter process flow, less stress for both animals and slaughterhouse personnel, improved carcase quality and an overall improved working environment. Several of the respondents reported rebuilding of the lairage area in order to create a buffer of animals to generate an even workflow and decreased stress when handling the animals. In some cases, rebuilding also enabled two active slaughter lines instead of one, which improved the slaughter process flow considerably and increased the ability to handle the animals in a non-stressful way.

However, animal welfare improvements were associated with high investment costs and the respondents noted that there were difficulties in measuring the pay-off from such improvements. Furthermore, the respondents did not believe that communicating with the public about the investments would increase sales. Some respondents argued that consumers, and the public in general, are not interested in the slaughter process as they live far from the reality of agriculture and food production. In addition, the respondents were not sure how they could internalise animal welfare in their economic decision-making.

Themes emerging from the focus group interviews

During interviews, we probed the respondents about aspects that they consider can contribute to both animal welfare and slaughterhouse profitability. Based on the interview material, we then identified six main themes. The respondents were asked to describe previous and planned investments in animal welfare improvements at their slaughterhouse and the expected economic effect, as well as the expected effect on animal welfare (Table S2).

Theme 1 General views on existing legislation, regulations and different standards

The respondents stated that the current animal welfare regulations can be difficult to implement and carry additional costs for slaughterhouses. One respondent highlighted the issue of transporting high-lactating cows from distant rural areas. According to the legislation (EC 2009), cows must be milked every 12 h. In practice, this may mean that the transporter cannot make any further stops on the route, and hence the transport costs increase.

The Swedish National Food Agency employs official veterinarians (OV) to monitor different aspects of the slaughter process at Swedish slaughterhouses. Individual differences in animal welfare assessment approach and thresholds between different OV inspectors have been reported (Arzoomand *et al* 2019) and were perceived by the respondents to affect the recorded level of non-compliance recorded or requests for correction, which may influence the costs. One respondent argued that the variation in OV inspectors' assessments could involve a risk of the slaughterhouse getting a bad reputation, potentially leading to a shortage of animals if farmers instead chose to deliver their animals to other slaughterhouses.

The respondents pointed out that there are different standards and certifications intended to increase animal welfare on the market and that the economic outcome for slaughterhouses can be affected by these if they comply with stated requirements and pay a membership fee. Although the intention is to increase animal welfare and encourage better decision-making by consumers at the point of purchase, some respondents claimed that the costs exceed the benefits for slaughterhouses. In addition, some farmers have their own standards that the slaughterhouse needs to take into consideration, which can complicate the slaughter process and requires increased efforts by slaughterhouse personnel.

Theme 2 Farm-level effects on animal welfare in slaughterhouses

In response to probing about the implications of animal welfare for the economic outcome for slaughterhouses, the respondents reported that animals' prior experiences in life play a crucial role in how they experience the situation at the slaughterhouse. The respondents generally believed that animals raised in extensive ranch-drift systems are more difficult to handle than those raised in intensive systems and that they display more stress on entering the slaughterhouse, probably due to limited prior contact with humans and indoor environments (Hemsworth *et al* 2011). In addition, all respondents stressed the responsibility of farmers for handling animals properly on-farm.

The respondents identified mixing of animals on-farm before transport to the slaughterhouse as a key issue for animal welfare, with animals with no prior relation to each other tending to fight and express stress-related behaviours during the transport and after arrival at the slaughterhouse. The respondents claimed this to be one of the main reasons for meat quality problems such as DFD or PSE. Another issue that several respondents pointed out was dirty animals arriving at the slaughterhouse, since this restricts the potential for hygienic slaughter. When de-hiding those animals, contamination is unavoidable and usually leads to condemnation of some or all of the carcase.

Theme 3 The role of proficient transporters

The respondents reported that proficient transporters with experience and a good understanding of animals and animal handling legislation, have a great impact on animal welfare and on the economic outcome for the slaughterhouse. Currently, no specific legislation exists regulating the loading facilities on-farm, which respondents viewed as problematic. In many cases, the same loading facilities are used for both cattle and pigs and transport drivers have to be flexible and solution-oriented when using these facilities, due to the large differences between the species. The respondents highlighted a need for optimising transport logistics but recognised that this is not always feasible. Another animal welfare-related cost mentioned by the respondents was severely sick or injured animals that have to be euthanased, either on the transport vehicle or in lairage. These animals are subject to total condemnation and cannot pass through the slaughter process, which is not only a waste of resources, ie meat and money, but also raises concerns about animal health, and thus animal welfare. This relates to the important issue of animals being fit for transport and slaughter and, not least, consumption.

Theme 4 Impact of slaughter process flow on productivity

The respondents described the workflow at slaughter as critical for productivity and for providing an acceptable work situation for slaughterhouse personnel. A good workflow is dependent on a good animal flow, which is closely linked to animal welfare. Likewise, maintaining a slaughter process speed that is adapted to the design and technical constraints of the slaughterhouse is essential. The respondents claimed that having a mechanical system for handling animals is key to achieving an even workflow. For animals with limited experience of being handled, they also claimed that an automatic driving system improves animal welfare since the human-animal interaction is reduced. One of the respondents explained that Danish slaughterhouses have different automated production lines depending on pig weight and believed that this improves animal welfare and decreases the cost of labour. Many respondents reported that one of the main reasons for frustration among personnel, as well as possible implications for the economic outcome, is unplanned disturbances in the slaughter process, eg animals

https://doi.org/10.7120/09627286.31.4.004 Published online by Cambridge University Press

not accustomed to being handled. Thus, they believed it would most likely be beneficial for both slaughterhouse personnel and animals if the design were revised to facilitate easy driving to improve animal flow. Some of the main design features that the respondents specified were drive-race design, flooring and the overall lairage environment (eg barriers that prevent cattle from mounting each other). In addition, they believed that daily maintenance is fundamental in order to detect problems that need to be corrected.

The respondents considered overnight lairage at the slaughterhouse to be optimal for achieving an even slaughter process flow, and thus animal flow and workflow, although they were unsure about whether keeping animals in lairage overnight had positive or negative consequences for animal welfare. However, they reported that if animals can rest after transport, they are usually calmer to handle than if they are driven to the stun box immediately. One respondent reported that their slaughterhouse had a system for recording animal behaviour at night-time and that personnel with training in animal welfare visit the lairage in order to detect stressed individuals.

As mentioned, stress in animals before slaughter can lead to meat being discarded. The respondents reported that fighting in the lairage can lead to bruising, which must be removed from the carcase after stunning and de-bleeding, thus affecting the economic outcome. Several of the respondents reported greater problems with process-induced PSE in pigs (too-slow carcase cooling process) than with stress-induced PSE. Therefore, investment in new animal welfare-friendly equipment and drive-races was not expected to generate a lower prevalence of PSE carcases, although improved levels of animal welfare were expected.

Theme 5 The effect of experienced slaughterhouse personnel

The respondents emphasised that having a sufficient number of properly trained personnel is key for slaughterhouse productivity. They also claimed that the Swedish labour legislation can prevent managers from moving or removing unproductive personnel displaying negative, stressful handling behaviours to the animals before slaughter, which affects the economic outcome in several ways. Furthermore, having a safe and good working environment makes it easier to retain personnel. Some of the respondents highlighted the impact of continuous training of personnel, although the respondents did not view education on the principles of animal behaviour and methods of humane handling as a direct animal welfare improvement that might have implications for the economic outcome. However, some respondents reported that they occasionally provide standardised training sessions, and several respondents expressed an interest in further practical education in handling and slaughter techniques for their employees.

Theme 6 Importance of well-established dialogue between farmers, transporters and slaughterhouse management

To maintain an even flow of animals arriving at, and progressing through, the slaughter process, the respondents emphasised the need for slaughterhouse management to plan incoming animal deliveries with care. To do so, slaughterhouse management needs to have a well-established dialogue with the following actors:

- Farmers, who should send the correct number of animals (as pre-notified) to the slaughterhouse and, more importantly, only send animals in good condition for transport and slaughter. Animals that stay in lairage overnight also need to be in good condition.
- Transporters, who should transport healthy animals that are fit for transport. The transportation company also has a responsibility to optimise the transport route in order to be on time and maintain an even animal flow.
- Slaughterhouse personnel, who should provide information about when and where problems occur in the slaughter process, so that the right corrective measures can be taken, or future investments can be planned.

Discussion

We developed an economic model for slaughterhouses specialising in bovine and porcine slaughter processes and mapped the possible impact of animal welfare improvements on the economic consequences for the slaughterhouse business. In the economic model, we introduced animal welfare as a production factor in the production function of the model, in a similar way to other factors used in production (eg material, labour). In particular, we considered investments in animal welfare improvements as an intangible asset that contributes to the economic outcome. Previous studies have pointed out the importance of intangible assets when estimating business production functions in order to obtain consistent estimates for the inputs included (Marrocu *et al* 2012). Considering intangible assets is not standard in production economic models, but was done by Telldahl *et al* (2019) in a study estimating the impact of animal health on dairy production, which found that impaired animal health clearly resulted in loss of economic output. We validated the economic model and assessed the impacts of animal welfare improvements on the economic outcome, in two focus group interviews with slaughterhouse personnel. Thus, our formal model was tested in a qualitative framework, rather than in the econometric framework, which is the standard approach for testing economic models. We found that this exploratory setting was useful to discuss in depth: (i) how the economic systems in slaughterhouses function; and (ii) slaughterhouse personnel's perceptions on how animal welfare affects the economic outcome for the slaughterhouse. Thus, the focus group interviews functioned to validate the economic model in the study situation, where it was not possible to obtain the type of large-scale data typically used for econometric analysis.

This study adds to the existing scientific literature in the field by introducing an economic model for slaughterhouses that can be used in future research as a basis for mapping the economic impact of animal welfare and, for example, in scenario analysis of various animal welfare interventions and their economic consequences for slaughterhouses. Few previous studies have focused on the importance of animal welfare for the economic outcome at slaughter (Grandin 1995; Gallo & Huertas 2015; Wigham *et al* 2018). A common conclusion is that there are several economic consequences of impaired welfare at slaughter, eg increased labour requirements and line stoppages. However, ours is the first study to develop a model based on a profit function to describe the relationship between animal welfare and the economic outcome for slaughterhouse businesses.

In qualitative focus group interviews to validate the model, the respondents stressed the importance of profitable by-products and of continuous exploration of new areas that contribute to the economic outcome, and the magnitude of that contribution, rather than the profits obtained from selling the carcases. The quality of the carcase and by-products has a direct link to animal welfare, as physical injuries to the live animal (eg bruises and blood splashes) and stress-related meat quality problems such as PSE and DFD can be indicators of impaired welfare and generate a loss of income due to condemned meat. In the focus group responses, the main expected economic effects of improved animal welfare at slaughter were reduced labour costs due to easier handling procedures and better-constructed lairage facilities, drive-races and stun boxes, and overall enhanced productivity. The respondents confirmed that investing in animal welfare improvements, eg through redesign of the slaughterhouse interior and improving the efficiency of the slaughter line, can contribute to a positive economic outcome through reduced labour costs. The results also indicated that investing in animal welfare improvements is an essential part of the slaughterhouse business, although sometimes difficult to measure in a precise manner.

Furthermore, all slaughterhouses represented in the focus groups had invested, or were planning to invest, in animal welfare improvements, even when not legally required to do so (Table S2). New drive-race designs for both cattle and pigs were assumed to improve animal welfare by lowering stress in the animals during handling, supporting findings by Hultgren *et al* (2014). This can be expected to improve the slaughter process flow, as the flow of animals is increased, and to lower the number of staff required (Grandin 1995), thus having an expected direct effect on the economic outcome. However, the respondents reported uncertainty about measuring the economic effects in these terms. Furthermore, the effect on animal welfare could be indirect; with a workflow improved, personnel are less stressed when handling the animals, which leads to calmer handling procedures. One respondent reported that a recent animal welfare investment, involving re-design of the unloading area and improved design of the drive-race to the stunning box for cattle, had an effect on slaughterhouse profitability due to improved meat quality. This is in line with Alleweldt *et al* (2007), who found that improved meat quality could compensate for investment costs, despite slightly elevated operating costs.

Formal training of slaughterhouse personnel handling animals is currently based on theory (EC 2009), and the respondents wanted access to additional practical training in pre-slaughter handling and slaughter techniques, since this is important for the learning outcome. Several of the slaughterhouses represented already provide sporadic standardised training sessions, but the respondents in question did not see any direct link to economic output. On the other hand, they pointed out the importance of having a sufficient number of properly trained personnel as key to productivity. Other studies have indicated that training to improve animal handling could result in significant positive economic effects at slaughterhouse level, due to increased revenue from higher quality meat (Alleweldt *et al* 2007; Coleman *et al* 2012). Management therefore plays a crucial role for the slaughterhouse business (Grandin 2013). The respondents emphasised that managers need to have a well-established dialogue with slaughterhouse personnel, but also with farmers and transporters. If managers emphasise the importance of handling animals properly, generally advocate fair treatment of animals and employees, encourage training and actively seek to invest in appropriate slaughterhouse infrastructure to achieve this whenever possible, this may improve the general attitude at the slaughterhouse, hence resulting in improved animal welfare (Grandin 1995).

The respondents also highlighted the importance of farm animals' prior experiences in life. They all mentioned farmers' responsibility for handling the animals well on-farm and reported a link between stress-related behaviours from animals with no prior experiences of being handled and economic performance. Animals with previous rough handling experiences may also be more stressed when handled at the slaughterhouse compared with animals that have been handled in an animal-friendly way (Grandin 1997). The respondents mentioned difficulties with handling cattle and pigs from different rearing systems in slaughterhouse drive-race facilities. They reported that cattle reared in extensive systems are more difficult to handle than dairy cows reared in intensive systems, since they have limited experiences of, eg drive-races. Pigs reared on organic farms are reported to have more difficulty coping in crowded situations, eg during transport and in slaughterhouses, than pigs from conventional farms (Thorell & Wallenbeck 2012). Farmers also have an obligation to sort out the animals from the farm that are fit for the slaughter chain at any given point in time (transport, slaughter, processing etc). Future studies should investigate the possible relationship between animal handling, meat quality problems and economic outcome in relation to rearing system.

In addition to directly affecting product quality, impaired animal welfare at slaughter can be seen as a negative external effect of the economic activities that take place at the slaughterhouse. This holds also for poor animal welfare

https://doi.org/10.7120/09627286.31.4.004 Published online by Cambridge University Press

at farms, according to McInerney (2004). Unless there are costs or foregone revenues associated with impaired animal welfare at slaughterhouse business level, the financial incentive to account for the negative external effects associated with poor animal welfare can be expected to be small. Therefore, the level of animal welfare provided by slaughterhouses may be lower than is desirable from a societal point of view. This means that various policy measures may be needed to incentivise investments to improve animal welfare, bearing in mind that:

• Unless slaughterhouses can find ways of increasing their revenues, they have little financial incentive to improve animal welfare beyond legal requirements. Animal welfare improvements were often associated with high investment costs and respondents reported difficulty in measuring the direct pay-off in terms of sales. Considering the investment constraints of slaughterhouses, animal welfare decisions should be discussed before new slaughterhouses are constructed or modernised. Our focus groups interviews indicated the opposite: animal welfare is not considered until after a slaughterhouse has been built or modernised.

• Investments in animal welfare improvements could be used for marketing purposes, but respondents highlighted an issue with branding investments in animal welfare due to lack of consumer and societal knowledge about the slaughter process. Interestingly, the respondents expected no increase in sales if they communicated the investments to the public. This is an obstacle for the slaughterhouse business, because if consumers do not have sufficient information they cannot contribute to an effective market solution (Lusk 2011). The literature suggests that consumers associate high food quality with higher animal welfare and are willing to pay more, especially if they are provided with information about rearing conditions of the animals and animal welfare (Napolitano *et al* 2008; Lagerkvist & Hess 2011). This raises the overall question of market failure through slaughterhouses experiencing difficulties with communicating what they are doing and how they are producing.

• Grants and investment support are one way of encouraging changes in production methods when the current market solution alone cannot promote the use of new methods. Such support could be based on compliance with several animal welfare and environmental practices, including the aspects considered in this study. From a policy perspective, there may be a need to provide a more diversified set of support payments that compensate for animal welfare costs and encourage better animal welfare directly in slaughterhouses. It is also important for slaughterhouse businesses to be transparent about their production process and to acknowledge the possibilities with branding their investments in animal welfare improvements.

There are some limitations of the study, eg we only interviewed Swedish slaughterhouse personnel working with quality assurance schemes and slaughter managers, and there was a clear division of females and males between these two positions, which demonstrates that this is a structural characteristic of the slaughterhouse sector. From a societal perspective, however, the respondents were not a representative selection of people. Future studies should therefore expand the interviews to include financial managers at slaughterhouses. Further, the study was conducted in Sweden, which has relatively strict animal welfare regulations and high animal welfare expectations from citizens and consumers. The temperate climate in Sweden creates a need for climate-controlled housing for pigs, and during a large part of the year for cattle, leading to high production costs related to housing. This has possible effects on handling and animal welfare at slaughter. Thus, the results need to be interpreted in relation to the Swedish conditions. The study includes slaughter of cattle and pigs and the situation, circumstances and relationships between animal welfare at slaughter and slaughterhouse economy may be different for other species. The slaughterhouses included in the study represented around 7% of the total Swedish slaughterhouses and varied in size from small- to large-scale. The main strength of this study was to describe the relationship between animal welfare and the economic outcome for slaughterhouse businesses.

Animal welfare implications and conclusion

This study is the first to: (i) develop an economic model to describe the impact of animal welfare at slaughter; (ii) map the possible economic effects of animal welfare improvements; and (iii) illustrate how the production function can be affected when animal welfare is improved. Focus groups' interviews revealed that the workflow in slaughterhouses is critical for productivity and that an even flow of animals improves the economic outcome, the work environment and animal welfare. To improve the process flow, the slaughterhouses invest in animal welfare improvements, eg improved drive-races and stunning equipment, which decreases pre-slaughter stress in animals and can contribute positively to the economic outcome through reduced prevalence of meat discards. We found that all slaughterhouses had invested in animal welfare improvements but had difficulties with developing methods to measure the economic effects. The slaughterhouses also found it difficult to brand their animal welfare improvements to consumers and society, due to limited possibilities for branding and marketing the (controversial) slaughter procedure. We identified a lack of motivation to internalise animal welfare in the decision-making process of the slaughterhouse business. On the other hand, we identified potential to implement different policy measures in order to exploit the economic effects of improved animal welfare. Lastly, animal-friendly handling in the slaughterhouse is vital, although focus group respondents believed that farmers play an equally vital role in handling animals on-farm, as this affects handling in the slaughterhouse. Our economic model provides a foundation for future research on the economic effects of animal welfare at slaughter and can be a useful tool for revealing the impact of animal welfare as an intangible asset, especially if complemented with animal welfare data from slaughterhouses.

Declaration of interest

The funder FORMAS has no influence on the study. The authors do not have any conflict of interest. Furthermore, the authors are neutral and objective in relation to the participating slaughterhouses.

Acknowledgements

This study was funded by FORMAS 2018-01134. The co-operation of the participating slaughterhouses is greatly appreciated.

References

Ahmed H, Alvåsen K, Berg C, Hansson H, Hultgren J, Röcklinsberg H and Emanuelson U 2020 Assessing economic consequences of improved animal welfare in Swedish cattle fattening operations using a stochastic partial budgeting approach. *Livestock Science 232*: 103920

Alexandratos N and Bruinsma J 2012 *World agriculture towards 2030/2050: the 2012 revision*, *Volume 12, No 3*, *ESA Working paper*. FAO: Rome, Italy

Algers A and Berg C 2017 Open knowledge about slaughter on the internet — a case study on controversies. *Animals 7*: 1-11. https://doi.org/10.3390/ani7120101

Alleweldt F, Kara S, Schubert K, Fries R and Großpietsch R 2007 Study on the stunning/killing practices in slaughterhouses and their economic, social and environmental consequences. *Final Report, Part 1: Red Meat. European Commission* pp 166. Directorate General for Health and Consumer Protection: Brussels, Belgium

Alonso ME, González-Montaña JR and Lomillos JM 2020 Consumers' concerns and perceptions of farm animal welfare. *Animals 10*: 1-13. https://doi.org/10.3390/ani10030385

Alvåsen K, Hansson H, Emanuelson U and Westin R 2017 Animal welfare and economic aspects of using nurse sows in Swedish pig production. *Frontiers in Veterinary Science 4*. https://doi.org/10.3389/fvets.2017.00204

Arzoomand N, Vågsholm I, Niskanen R, Johansson A and Comin A 2019 Flexible distribution of tasks in meat inspection – A pilot study. *Food Control 102*: 166-172. https://doi.org/10.1016/j.foodcont.2019.03.010

Atkinson S, Velarde A and Algers B 2013 Assessment of stun quality at commercial slaughter in cattle shot with captive bolt. *Animal Welfare 22*: 473-481. https://doi.org/10.7120/09627286.22.4.473

Braun V and Clarke V 2006 Using thematic analysis in psychology. *Qualitative Research in Psychology 3*: 77-101. https://doi.org/10.1191/1478088706qp063oa

Breuer K, Hemsworth PH, Barnett JL, Matthews LR and Coleman GJ 2000 Behavioural response to humans and the productivity of commercial dairy cows. *Applied Animal Behaviour Science 66*: 273-288. https://doi.org/10.1016/S0168-1591(99)00097-0

Carson D, Gilmore A, Perry C and Gronhaug K 2011 Focus group interviewing. *Qualitative Marketing Research*: 113-131

Chulayo AY and Muchenje V 2015 A balanced perspective on animal welfare for improved meat and meat products. *South African Journal of Animal Sciences 45*: 452-469. https://doi.org/10.4314/sajas.v45i5.2

Coleman GJ, Rice M and Hemsworth PH 2012 Human-animal relationships at sheep and cattle abattoirs. *Animal Welfare 21*: 15-21. https://doi.org/10.7120/096272812X13353700593329

Costa LN, Fiego DPL, Tassone F and Russo V 2006 The relationship between carcass bruising in bulls and behaviour observed during pre-slaughter phases. *Veterinary Research Communications 30*: 379-381. https://doi.org/10.1007/s11259-006-0086-9

Coyne LA, Pinchbeck GL, Williams NJ, Smith RF, Dawson S, Pearson RB and Latham SM 2014 Understanding antimicrobial use and prescribing behaviours by pig veterinary surgeons and farmers: A qualitative study. *Veterinary Record 175*: 593. https://doi.org/10.1136/vr.102686

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

European Community 2009 Council Regulation No 1099/2009 on the Protection of Animals at the Time of Killing. *Official Journal of the European Union L303*: 1-30

Fernandes JN, Hemsworth PH, Coleman GJ and Tilbrook AJ 2021 Costs and benefits of improving farm animal welfare. *Agriculture (Switzerland) 11*: 1-14. https://doi.org/10.3390/agriculture11020104

Fraser D, Weary DM, Pajor EA and Milligan BN 1997 A scientific conception of animal welfare that reflects ethical concerns. *Animal Welfare 6*: 187-205

Gallo C, Teuber C, Cartes M, Uribe H and Grandin T 2003 Improvements in stunning of cattle with a pneumatic stunner after changes in equipment and employee training. *Archivos de Medicina Veterinaria 35*: 159-170. https://doi.org/10.4067/S0301-732X2003000200004

Gallo CB and Huertas SM 2015 Main animal welfare problems in ruminant livestock during preslaughter operations: A South American view. *Animal 10*: 357-364. https://doi.org/10.1017/S1751731115001597

Gibson TJ and Jackson EL 2017 The economics of animal welfare. *OIE Revue Scientifique et Technique 36*: 125-135. https://doi.org/10.20506/rst.36.1.2616

Gori E, Chang TFM, Iseppi L, Goga BC, Iulietto MF, Sechi P and Lepellere MA 2017 The assessment of consumer sensitivity to animal welfare: An application of Rasch Model. *Rivista di Studi sulla Sostenibilita 1*: 107-127. https://doi.org/10.3280/RISS2017-001008

Grandin T 1995 The economic benefits of proper animal welfare. *48th Annual Reciprocal Meat Conference* pp 122-127. San Antonio, TX, USA. https://meatscience.org/docs/default-source/publications-resources/rmc/1995/the-economic-benefits-of-proper-animal-welfare.pdf?sfvrsn=2

Grandin T 1996 Factors that impede animal movement at slaughter plants. *Journal American Veterinary Medical Association 209*: 757-759

Grandin T 1997 Assessment of stress during handling and transport. *Journal of Animal Science 75*: 249-257. https://doi.org/10.2527/1997.751249x

Grandin T 2000 Handling and welfare of livestock in slaughter plants. In: Grandin T (ed) *Livestock Handling and Transport* pp 409-439. CAB International, Wallingford, UK. https://doi.org/10.1079/9780851994093.0409

Grandin T 2007 *Livestock Handling and Transport* pp 329-353. CABI: Wallingford UK. https://doi.org/10.1079/9781845932190.0329

Grandin T 2013 Making slaughterhouses more humane for cattle, pigs, and sheep. *Annual Review of Animal Biosciences 1*: 491-512. https://doi.org/10.1146/annurev-animal-031412-103713

Harley S, More S, Boyle L, O'Connell N and Hanlon A 2012 Good animal welfare makes economic sense: Potential of pig abattoir meat inspection as a welfare surveillance tool. *Irish Veterinary Journal 65*: 1-12. https://doi.org/10.1186/2046-0481-65-11

Hemsworth PH, Coleman GJ, Barnett JL, Borg S and Dowling S 2002 The effects of cognitive behavioral intervention on the attitude and behavior of stockpersons and the behavior and productivity of commercial dairy cows. *Journal of Animal Science 80*: 68-78. https://doi.org/10.2527/2002.80168x

Hemsworth PH, Rice M, Karlen MG, Calleja L, Barnett JL, Nash J and Coleman GJ 2011 Human-animal interactions at abattoirs: Relationships between handling and animal stress in sheep and cattle. *Applied Animal Behaviour Science 135*: 24-33. https://doi.org/10.1016/j.applanim.2011.09.007

Henningsen A, Czekaj TG, Forkman B, Lund M and Nielsen AS 2018 The relationship between animal welfare and economic performance at farm level: A quantitative study of Danish pig producers. *Journal of Agricultural Economics 69*: 142-162. https://doi.org/10.1111/1477-9552.12228

Holdstock J, Aalhus JL, Uttaro BA, López-Campos Ó, Larsen IL and Bruce HL 2014 The impact of ultimate pH on muscle characteristics and sensory attributes of the longissimus thoracis within the dark cutting (Canada B4) beef carcass grade. *Meat Science 98*: 842-849. https://doi.org/10.1016/j.meatsci.2014.07.029

Huertas SM, van Eerdenburg F, Gil A and Piaggio J 2015 Prevalence of carcass bruises as an indicator of welfare in beef cattle and the relation to the economic impact. *Veterinary Medicine and Science 1*: 9-15. https://doi.org/10.1002/vms3.2

Hultgren J, Wiberg S, Berg C, Cvek K and Lunner Kolstrup C 2014 Cattle behaviours and stockperson actions related to impaired animal welfare at Swedish slaughter plants. *Applied Animal Behaviour Science 152*: 23-37. https://doi.org/10.1016/j.applanim.2013.12.005

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

Leary S, Underwood W, Anthony R, Cartner S, Lilly E, Anthony R, Cartner S, Corey D, Clinic AV, Walla W, Grandin T, Collins F, Greenacre C, Gwaltney-Brant S, McCrackin MA, Polytechnic V, Meyer R, State M, Miller D, Shearer J, Yanong R, Golab GC, Division AW, Patterson-Kane E, Scientist AW and Division AW 2013 *AVMA Guidelines for the Euthanasia of Animals: 2013 Edition*. American Veterinary Medical Association: Schaumburg, IL, USA. https://www.in.gov/boah/files/AVMA_Euthanasia_Guidelines.pdf

Leonardsson H, Macgregor M and Bruckmeier K 2011 Report No 6: Trends and the future. *Developments in Animal Welfare*: 1-21

Losada-Espinosa N, Villarroel M, María GA and Miranda-de la Lama GC 2018 Pre-slaughter cattle welfare indicators for use in commercial abattoirs with voluntary monitoring systems: A systematic review. *Meat Science 138*: 34-48. https://doi.org/10.1016/j.meatsci.2017.12.004

Lusk JL 2011 The market for animal welfare. *Agriculture and Human Values 28*: 561-575. https://doi.org/10.1007/s10460-011-9318-x

Marrocu M, Paci R and Pontis M 2021 Intangible capital and firms' productivity. *Industrial and Corporate Change 21*: 377-402. https://doi.org/10.1093/icc/dtr042

McInerney J 2004 *Animal welfare, economics and policy*. Report on a study undertaken for the Farm & Animal Health Economics Division of Defra. https://scholar.google.com/scholar_lookup?title=Animal%20welfare%2C%20economics%20and%20policy&publication_year=2004&author=J

Napolitano F, Pacelli C, Girolami A and Braghieri A 2008 Effect of information about animal welfare on consumer willingness to pay for yogurt. *Journal of Dairy Science 91*: 910-917. https://doi.org/10.3168/jds.2007-0709

Telldahl C, Hansson H and Emanuelson U 2019 Modelling animal health as a production factor in dairy production- a case of low somatic cell counts in Swedish dairy agriculture. *Livestock Science 230*: 103840. https://doi.org/10.1016/j.livsci.2019.103840

Thorell K and Wallenbeck A 2012 Pig behaviour during crowding – a study in organic and conventional herds. *Nordic Symposium of the International Association of Applied Ethology (ISAE)*. 16-18 January 2012, Skara, Sweden

Warner RD, Ferguson DM, Cottrell JJ and Knee BW 2007 Acute stress induced by the preslaughter use of electric prodders causes tougher beef meat. *Australian Journal of Experimental Agriculture 47*: 782-788. https://doi.org/10.1071/EA05155

Wiberg S 2012 *Sveriges Lantbruksuniversitet Skara Avhandling 5 Institutionen för Husdjurens Miljö och Hälsa Avdelningen för Husdjurshygien.* [Title translation: Slaughter-not only about animals an interdisciplinary study of handling of cattle at slaughter]

Wigham EE, Butterworth A and Wotton S 2018 Assessing cattle welfare at slaughter – Why is it important and what challenges are faced? *Meat Science 145*: 171-177. https://doi.org/10.1016/j.meatsci.2018.06.010