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A quantitative study of Danish pig producers

Arne Henningsen
Tomasz Gerard Czekaj
Björn Forkman
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Department of Food and Resource Economics (IFRO)
University of Copenhagen
Rolighedsvej 25
DK 1958 Frederiksberg DENMARK
www.ifro.ku.dk/english/

The Relationship between Animal Welfare and Economic Performance at Farm Level: A Quantitative Study of Danish Pig Producers

Arne Henningsen[a*], Tomasz Gerard Czekaj[a], Björn Forkman[b], Mogens Lund[c], and Aske Schou Nielsen[a]

[a] Department of Food and Resource Economics, University of Copenhagen, Rolighedsvej 25, 1958 Frederiksberg C, Denmark

[b] Department of Large Animal Sciences, University of Copenhagen, Denmark

[c] Division for Food Production and Society, Norwegian Institute of Bioeconomy Research, Norway

[*] Corresponding author, e-mail: arne@ifro.ku.dk

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Author contributions:
Mogens Lund, Arne Henningsen, and Björn Forkman initiated the research and developed the general idea of the study. The literature review was mainly conducted by Aske Schou Nielsen and Arne Henningsen. The theoretical model was mainly developed by Arne Henningsen. The preparation, handling, and analysis of the data was conducted by Tomasz Gerard Czekaj, Arne Henningsen, and Aske Schou Nielsen. The article was mostly written by Arne Henningsen, Tomasz Gerard Czekaj, and Björn Forkman. All authors participated in the revision of the article.

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Abstract

We propose a theoretical framework for the relationship between animal welfare and the economic performance of livestock farms. We empirically analyse this relationship based on a unique data set of randomly sampled Danish pig herds that includes information from unannounced inspections of the compliance with the animal welfare legislation. We find large variations in economic performance indicators and animal welfare indicators. The relationship between these two indicators is rather weak, but tends to be slightly positive. We conclude that management has a major influence on both economic performance and animal welfare so that good farm managers are able to obey all animal welfare regulations and, at the same time, achieve a high economic performance.

Keywords: animal welfare, gross margin, technical efficiency, pig farms, Denmark

JEL codes: Q12

1 Introduction

Consumers and policy makers have become increasingly concerned about animal welfare, particularly in Europe and some other developed countries. As a response, the European Union and many national governments have sharpened regulations that are intended to guarantee a certain level of well-being for farm animals, laboratory animals, and/or pets (e.g. Bornett, Guy and Cain, 2003). A number of studies exist that investigate consumers' attitudes towards animal welfare and their willingness to pay for higher welfare of farm animals (e.g. Lusk and Norwood, 2011; Lagerkvist and Hess, 2011). However, very few studies investigate the economic aspects of animal welfare and animal welfare regulations on the production side. This is surprising because animal welfare and animal welfare regulations are often assumed to have a major effect on the competitiveness of animal production (e.g. Majewski et al., 2012; Harvey et al., 2013).

Most of the current studies of the relationship between animal welfare and economic performance are based on expert information or test stations, but their results have not yet been validated in commercial farms under real-world conditions. The few studies that are based on real-world farm-level data (to our knowledge only Lawson et al., 2004a, Lawson et al., 2004b, Barnes et al., 2011, and Stott et al., 2012) have all been done in the dairy or sheep sector and mostly use animal health indicators as proxies for animal welfare. Although animal welfare issues are more frequent on pig farms than on dairy farms (e.g. Hess et al., 2014), the relationship between animal welfare and economic performance has—to our knowledge—not yet been empirically analysed for pig farms. In order to close this gap in the literature, we empirically investigate the relationship between animal welfare and the economic performance of Danish pig farms.

Our paper contributes to the literature (i) by suggesting a theoretical framework for the relationship between farm management, animal welfare, and economic performance, (ii) by presenting one of the first empirical studies of the relationship between animal welfare and economic performance that uses information from animal welfare inspections (rather than animal health indicators), and (iii) by presenting the first empirical study of the relationship between animal welfare and economic performance on pig farms.

The next section provides background information and theoretical considerations on the legislative and economic aspects of animal welfare. Section 3 describes the data and methods used in this study. Sections 4 and 5 present and discuss, respectively, the results. Finally, Section 6 concludes.

2 Background

2.1 Animal welfare and animal welfare legislation

Animal welfare legislation is a compromise between, on the one hand, the desire to protect animal welfare and, on the other hand, economic and other costs, e.g. environmental constraints. The purpose of animal welfare legislation is, therefore, never to maximise animal welfare, but rather to set the lowest level of acceptable standards for a given species in a given situation. How situation-dependent animal welfare legislation is, is illustrated by the fact that the legislation may differ for the same species depending on whether the animals are to be kept as pets, laboratory animals or production animals.

Animal welfare can be measured by outcome-based measures, e.g. the number of scratches or wounds on an animal's body, or by resource-based measures, e.g. the stocking density (Botreau et al., 2007). There has been a recent increase in interest in outcome-based measures because they are thought to be closer to the experiences of the animal (Fraser, 2003). For example, the EU-funded Welfare Quality® project produced welfare assessment schemes using primarily outcome-based measures (for a discussion see Keeling, 2009). However, resource-based measures do have two advantages. The first is the predictability aspect, which is important for the due process of law. Farmers can easily control resource-based measures (e.g. number of pigs per pen or availability of hospital pens), while it is much harder for them to control outcome-based measures such as the level of tail biting or fighting (which results in scratches or wounds). The second advantage is the practicality of the measure because resource-based measures are generally faster and easier to assess than outcome-based measures. For these reasons, there is still a focus on resource-based measures in animal welfare legislation.

One consequence of legislation being concerned with minimum standards of animal welfare is that it is "the worst case" that is reported when evaluating non-compliance with the legislation. However, in animal welfare assessment, it is the aggregated value for all the animals on the farm that is usually reported. Non-compliance with animal welfare legislation, therefore, only says that there is a problem with animal welfare on a given farm, whereas an animal welfare assessment indicates the size of the problem.

2.2 Animal welfare and economics

Animal welfare is particularly related to four areas within the field of economics: public economics, welfare economics, consumer economics, and production economics (Lusk and Norwood, 2011). Public economics studies market failures, e.g. whether animal welfare has "public good" characteristics, which would justify government intervention such as stricter welfare legislation. Welfare economics examines the effects of different policies or initiatives on consumers, taxpayers and producers and makes use of both consumer economics and production economics. The aspect of animal welfare that has been most frequently analysed by economists is consumers' preferences for improved animal welfare (Lusk and Norwood, 2011, for a review see Lagerkvist and Hess, 2011).

Production economics can help to understand the producer's economic incentives for improving (or reducing) animal welfare. The producer is the caretaker of farm animals and his/her decisions regarding the housing system, feed quality, health management, etc. reflect his/her values on animal welfare, but also his/her desire to maximise profits. Knowledge of the relationship between economics and animal welfare can aid farm managers, consultants and policy makers in discussions on management strategies or in the implementation of new welfare legislation. However, currently there is a significant gap in the production economics literature concerning animal welfare (e.g. McInerney, 2004; Lawrence and Stott, 2009; Lusk and Norwood, 2011).

Most of the existing studies within production economics use a modelling approach based on expert information to assess the additional costs of production systems that increase the well-being of farm animals compared to currently prevailing production systems (e.g. Den Ouden et al., 1997; Bornett, Guy and Cain, 2003; Lund, Otto and Jacobsen, 2010; Seibert and Norwood, 2011; Vosough Ahmadi et al., 2011; Guy et al., 2012; Majewski et al., 2012; Harvey et al., 2013).[1] While most of these studies use resource-based animal welfare indicators, Jensen, Kristensen and Toft (2012) use outcome-based animal welfare indicators in their study, which uses expert opinions to investigate the effects of different causes of lameness on the severity of pain and profit losses in finisher pig production.

Only a few studies use empirical data to investigate the relationship between animal welfare and economic performance. These studies and their findings are summarised in Table 1. Stott et al. (2012) find a slightly positive relationship between animal welfare scores obtained from expert assessments and gross margin for their small sample of 20 purposely selected extensive sheep farms in Great Britain. Other studies use animal health as a proxy for the animals' well-being. Jensen et al. (2008) find a negative relationship between diseases (medical treatments and pathological lesions) and the gross margin of individual finishing boars at a test station. Finally, results based on empirical data from dairy farms in Denmark (Lawson et al., 2004a,b) and Great Britain (Barnes et al., 2011) are divergent and partly contradicting regarding the relationship between various animal health indicators (e.g. lameness, metabolic disorders, digestive disorders, reproductive disorders) and technical efficiency.

[1] Another (smaller) branch of literature in the area of production economics investigates farmers' attitudes to farm animal welfare (see, e.g., Hansson and Lagerkvist, 2014, for a current literature review) as well as the relationship between these attitudes and some productivity measures (see, e.g., Hemsworth et al., 2000, 2002; Waiblinger et al., 2006). Since these studies do not take into account the actual level of animal welfare on the farm and—if they refer to productivity at all—only consider partial productivity measures (e.g. milk produced per cow, piglets raised per sow) rather than more general economic performance indicators, we do not provide an extensive review of this branch of literature, but only direct interested readers to some important publications on this subject.

Thus, to our knowledge, empirical studies on the relationship between animal welfare and economic performance have been mainly conducted in the dairy sector and have mainly used animal health indicators as proxies for the animals' well-being. Although animal welfare issues are more frequent on pig farms than on dairy farms (e.g. Hess et al., 2014), real-world farm level data have not yet been used to empirically investigate the relationship between animal welfare and economic performance in the pig sector.

Table 1: Empirical studies on the relationship between animal welfare and economic performance

Study	Animals analysed	Found relationship between welfare indicators and economic indicators
Lawson et al. (2004a)	dairy cows at 514 farms in Denmark	no robust relationship between milk production technical efficiency and reproductive disorders
Lawson et al. (2004b)	dairy cows at 574 farms in Denmark	higher technical efficiency is associated with: - lower frequency of milk fever - higher frequency of lameness - higher frequency of ketosis - higher frequency of digestive disorders
Jensen et al. (2008)	5777 finishing boars at a test station in Denmark	higher gross margin is associated with: - no oral medical treatment - no parenteral medical treatment - no pathological findings
Barnes et al. (2011)	dairy cows at 80 farms in Great Britain	higher technical efficiency is associated with lower frequency of lameness
Stott et al. (2012)	sheep at 20 extensive sheep farms in Great Britain	higher gross margin is slightly associated with higher animal welfare scores (assessed by experts)

2.3 Theoretical Model

We illustrate the role of animal welfare in the production process in Figure 1. The management of the farm decides on the type and quantity of inputs (e.g. buildings, equipment, labour time, feed, veterinary products and services), which are used in the production process to generate the outputs (e.g. piglets, slaughter pigs). Apart from the indirect effect on the production process through the use of inputs, the management also directly influences the production process, for instance, through their knowledge and skills and by prioritising different objectives (e.g. preventing sickness and mortality of animals, timely treatment of sick animals, regular working hours). Animal welfare is determined by the production process and, thus, is influenced by the management both through their input decisions (e.g. type of building, type of equipment, space per animal, rooting and manipulable materials, medicine for preventing and curing diseases) and their direct influence on the production process (e.g. prioritisation of animal welfare, time until sick animals are treated, knowledge, skills). The production process not only affects animal welfare, but animal welfare also affects the production process because the health and well-being of the animals affect their productive performance (e.g. growth, mortality rate). Hence, the output quantities directly depend on the production process and indirectly depend on animal welfare, input use, and the management.[2]

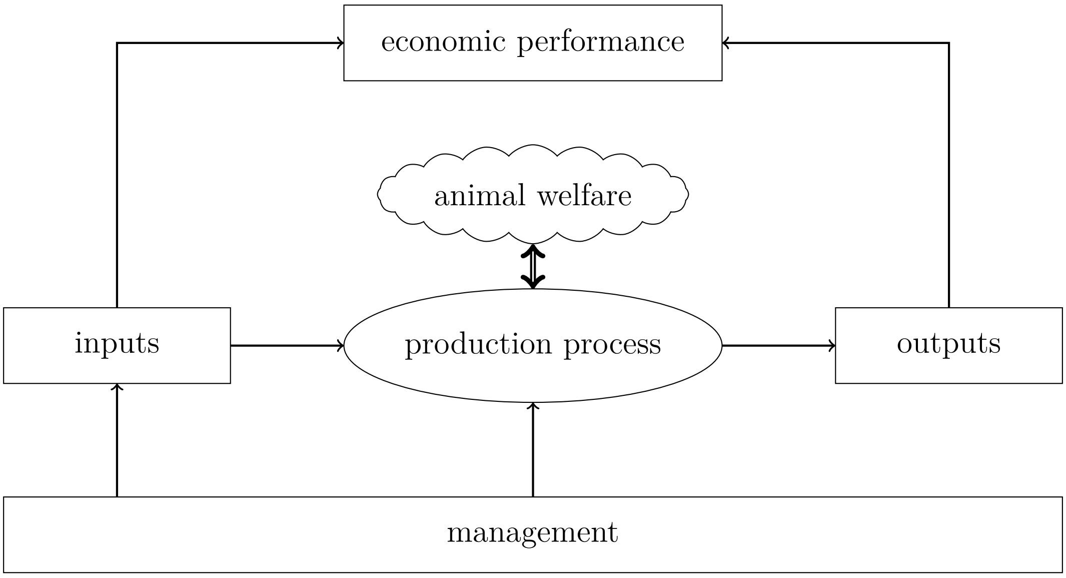


Figure 1: Role of animal welfare in the production process

Economic performance indicators are generally calculated based on the use of inputs and the production of outputs.[3] Hence, they are related to animal welfare through the production process and the outputs and they are influenced by the management through several channels. Our theoretical illustration suggests that economic performance does not have a direct causal effect on animal welfare. It may be argued that high or low

[2] One could argue that the production process and, hence, indirectly animal welfare, affects the use of inputs, for instance, because unhealthy animals with low animal welfare may require more veterinary products and services. However, it may also be argued that the farm manager *a priori* decides on a specific way of production with specific input quantities (e.g. equipment, labour time, veterinary products and services) and a specific (anticipated) level of animal welfare. In this case, the production process, and hence, animal welfare, would only affect the use of inputs in cases of unexpected exogenous shocks such as extraordinary disease outbreaks. Therefore, we argue that the input use affects the production process, but under normal circumstances the production process does not affect the use of inputs.

[3] Economic performance can be indicated by various measures, e.g. productivity (ratio between aggregate output quantity and aggregate input quantity), technical efficiency (ratio between observed output quantity and the maximum output quantity that can be obtained with the observed input quantities), profit (total revenues from outputs minus total costs of inputs), or gross margin (total revenues from outputs minus costs of variable inputs).

economic performance could affect the farm manager's motivation and his/her decisions, which in turn affect animal welfare. However we consider such effects to be negligible.[4]

Based on our theoretical model summarised in Figure 1, we take a closer look at the relationship between animal welfare and economic performance in Figure 2.[5] At an extremely low level of animal welfare A, the animals suffer so much (e.g. due to an insufficient provision of space, care, feed, or veterinary services) that only a very low economic performance level P_A can be achieved (e.g. due to sickness, high mortality). With increasing animal welfare up to level B, the positive effect of increased output quantities (e.g. due to higher growth rates, higher reproductive rates, lower mortality) is larger than the negative effect of increased input quantities (e.g. more space, more care, better veterinary services) so that economic performance increases until it reaches its maximum P_B. If animal welfare is increased above level B, e.g. to level D, the negative effect of increased input quantities (e.g. more space per animal, better access to rooting and manipulable materials) is larger than the positive effect of increased output quantities or the output quantities could even remain unchanged or decrease, so that the economic performance decreases, e.g. from P_B to P_D.[6]

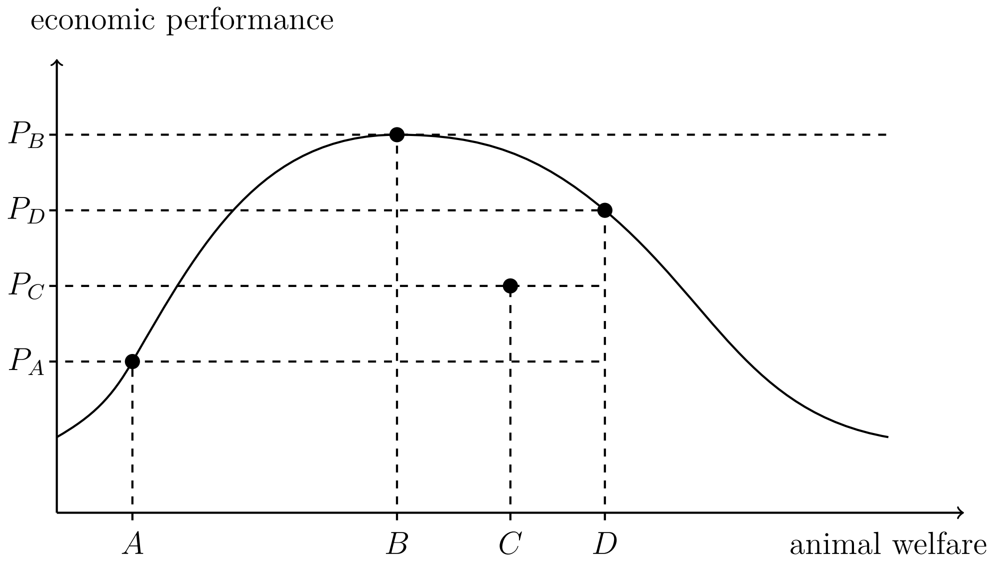


Figure 2: Relationship between animal welfare and economic performance

[4] It may also be argued that—in a dynamic setting—the production process, the output, and the economic performance may affect the management (quality) through feedback and learning. However, in our static model, we consider these effects to be negligible.

[5] This figure is somewhat similar to Figure 3 in McInerney (2004). We consider our model to be more helpful as a theoretical basis for our empirical analysis than the model of McInerney (2004). For instance, our model does not require the specification of a unique "unacceptable level of animal welfare," which is impossible to objectively define in practice as different people have different perceptions of what is an acceptable and what is an unacceptable treatment.

[6] As animal welfare is a multidimensional concept, the relationship between animal welfare and economic performance as illustrated in Figure 2 has, in practice, more than two dimensions. In this case, the maximum economic performance is achieved by a certain combination of levels of the different dimensions of animal welfare (e.g. B_1 = space per animal, B_2 = measures to prevent sicknesses, . . . , B_K, where K is the number of dimensions of animal welfare).

In the absence of any regulations or incentives regarding animal welfare, farm managers who are only interested in maximising economic performance would choose the animal welfare level B in Figure 2 so that economic performance is maximised at level P_B. If the animal welfare legislation requires a minimum level of animal welfare that is above the economic performance maximising animal welfare level B, say level D, the animal welfare legislation reduces economic performance from P_B to P_D. In this case, there should be a negative relationship between animal welfare and economic performance: farm managers who obey the animal welfare legislation achieve economic performance level P_D, while farm managers who do not obey one or more regulations of the animal welfare legislation achieve a higher economic performance (up to P_B).

These considerations assume that the farm managers always achieve at least the economic performance maximising animal welfare level B. However, if some farm managers do not manage to achieve the economic performance maximising animal welfare level B, but only achieve animal welfare level A and economic performance level P_A, there could be a positive relationship between animal welfare and economic performance.

Our above considerations also assume that the farm managers always achieve the maximum economic performance for a given level of animal welfare (as indicated by the solid line in Figure 2). However, some farm managers with insufficient management skills may not manage to fulfil the animal welfare legislation and, at the same time, fail to achieve the maximum economic performance for their level of animal welfare, which is indicated by animal welfare level C and economic performance level P_C in Figure 2. If the well-qualified farm managers produce at animal welfare level D and economic performance level P_D, while the insufficiently qualified farm managers produce at animal welfare level C and economic performance level P_C, a positive relationship between animal welfare and economic performance could arise.

Our theoretical considerations in this section indicate that there could be a positive, neutral, or negative relationship between animal welfare and economic performance. Our empirical analysis investigates the direction and extent of this relationship on Danish pig farms.

3 Data and methods

3.1 Animal welfare data

In 2011, the Department of Large Animal Sciences at the University of Copenhagen assessed—on behalf of the Danish Food and Veterinary Administration—the compliance of Danish pig farms with the animal welfare legislation (Anonymous, 2012). At that time, there existed 7,794 registered pig herds with ten or more animals in Denmark (excluding zoological gardens and animal shows). Out of these 7,794 herds, 300 herds were randomly selected for an unannounced visit by an animal welfare inspector. One of the 300 herds was discovered to have only two pigs at the time of the visit and the total sample size was, therefore, 299 herds. The size of the herds in the study ranged from 10 pigs to 9,420 pigs at the time of the visit, with an average of 1,703 pigs. The majority of herds consisted of slaughter pigs only (176 herds) or a mix of sows, piglets, and slaughter pigs (91 herds). There were also 24 pure sow and piglets herds and 8 pure piglets herds (Anonymous, 2012). Six herds were inspected by technicians from the Ministry of Food, Agriculture and Fisheries, while the remaining 293 herds were inspected by veterinarians. All veterinarians and technicians who took part in the study were engaged in animal welfare control as part of their daily occupation and participated in a calibration meeting, during which the different measures were discussed. At the meeting, each section of the pig farm was discussed with a representative of the "travelling inspectors" (Danish: "*Rejseholdet*," i.e. a group of veterinarians who participate in specific campaigns to control compliance with animal welfare regulations). The specific codes to be used in the inspections were also discussed to ensure a standardised recording. According to the Danish legislation, there are three levels of sanctions: admonition, decree and police report. An admonition only consists of advice to enable the farmer to follow the letter of the law. A decree either results in a second inspection or requires a written explanation of how and when the non-compliance was dealt with. If the farmer does not follow the required directions, he/she is reported to the police. A police report is also given for serious non-compliance with the animal welfare legislation, e.g. a chronically sick animal that is not in a hospital pen or is not being treated (The Danish Veterinary and Food Administration (DVFA), 2013, p. 34). The two most common areas of non-compliance were furnishing of adequate rooting and manipulable materials (24% of all herds) and treatment and handling of sick animals and the furnishing of the hospital pens (19% of all herds). A final area of non-compliance of relevance to animal welfare is the general paragraph that requires that animals should be managed properly and protected against suffering. Non-compliance in all three areas can, depending on the severity of the transgression, result in either an admonition, decree or police report (Anonymous, 2012; The Danish Veterinary and Food Administration (DVFA), 2013).

3.2 Economic data

The economic data that are used in our analysis were provided by the Danish Pig Research Centre in collaboration with the Knowledge Centre for Agriculture in Denmark, currently known as SEGES[7]. SEGES has accountancy data from a very large proportion of all commercial farmers in Denmark and we obtained the data for all farms in their database for which animal welfare data were available. The data that we received include

[7] On 1 January 2015, the Knowledge Centre for Agriculture and the Danish Pig Research Center merged and formed SEGES, which is a limited partnership company owned by the trade organisation Danish Agriculture and Food Council (the Danish farmers' trade organisation).

information on the number and type of produced pigs, the age of the farmer and the number of years the farmer has managed the farm (as proxies for experience) as well as variables that indicate the produced outputs and used inputs of the farm. We divided total farm output into two categories: animal output (which is mainly pig output) and other output (which is mainly crop output). Both outputs are measured as net value of production (in 1,000 DKK). We considered six categories of inputs: agricultural land (in hectares), feed (in 1,000 DKK), intermediate pig inputs (mainly veterinary products and services, in 1,000 DKK), other intermediate inputs (e.g. seeds, fertilisers, pesticides, in 1,000 DKK), labour (in hours), and capital (user costs of capital, in 1,000 DKK). Descriptive statistics of these variables are presented in Table 5.

3.3 Merging animal welfare data and economic data

While the economic data are observed on the farm level (id number of the farm in the Danish Central Business Register, Danish: *Det Centrale Virksomhedsregister*, CVR), the animal welfare data are observed on the herd level (id number of the physical farming location in the Danish Central Husbandry Register, Danish: *Det Centrale Husdyrbrugsregister*, CHR), where a single farm (CVR number) can own more than one herd (CHR numbers).

In total, we have animal welfare data for 299 herds, which belong to 292 different farms. We obtained economic data for 155 out of the 292 farms, for which we have animal welfare data. However, we found implausible values in the data of 19 farms.[8] Therefore, we could only use the economic data of 136 farms. If a farm has more than one herd (88 farms out of the 136 farms), we had to aggregate the animal welfare data to the farm level before we could merge it with the economic data. If a farm has more than one herd, but animal welfare data are only available for one of the herds (84 farms), we used the animal welfare data obtained at the one herd, assuming that this is representative for all herds on this farm. In the case of the 4 farms for which animal welfare data are available for more than one herd, we used the most severe sanction (police report > decree > admonition > no sanction) at each point of the checklist for compliance with the animal welfare legislation.

It is important to note that although the herds for which we have animal welfare data are randomly selected, the farms in the economic dataset are not randomly selected so that the merged data set that we used for our analyses is not necessarily a random sample of Danish pig farms. Section 4.1 presents the results of conducted formal statistical tests for possible non-random selection bias of our sample.

[8] As the gross margin is calculated based on several input and output variables, implausible values in one or more of these variables usually result in implausible values for the gross margin per livestock unit (LU). As the gross margin per LU is also one of our indicators of economic performance, we primarily use this variable to identify outliers. 19 farms have a gross margin per LU that is smaller than the first quartile minus 1.5 times the interquartile range (-1,143 DKK per LU) or larger than the third quartile plus 1.5 times the interquartile range (31,283 DKK per LU) and we removed these farms as outliers. After removing these 19 farms, we did not find any implausible values in the other variables of the remaining 136 farms.

3.4 Statistical and econometric methods

Our empirical analysis consists of four parts.

First, we use Welch's two-sample t-test (Welch, 1947) and Fisher's exact test (Fisher, 1935) to check whether the removal of herds due to non-availability of economic data has significantly affected the variables in our merged data set, i.e. to what extent our final data set can still be seen as a random sub-sample of the complete (randomly sampled) animal welfare data set. We test whether the mean values of continuous variables (e.g. herd size, number of violations of the animal welfare legislation) and the shares of categorical variables (e.g. production type, dummy variables indicating violations of specific parts of the animal welfare legislation) significantly differ between the herds that are included in our analysis and the herds that had to be excluded from the analysis because of the non-availability of economic data.

Second, we investigate the correlation between animal welfare indicators and economic performance by using boxplot diagrams, scatter plots, and Pearson's correlation coefficient. We use the gross margin per livestock unit (LU) (GM) as an indicator of economic performance and five different indicators of animal welfare: the total number of violations of the animal welfare legislation ($TotNViol$), the most severe sanction for violations of the animal welfare legislation (police report > decree > admonition > no sanction), and three dummy variables indicating violations of any of the animal welfare legislations ($AnyViolation$), violations of the animal welfare legislation regarding the provision of rooting and manipulable materials (e.g. for rooting, biting, chewing, etc.) ($AnyRooting$) and violations regarding the treatment of sick animals ($AnySick$), respectively. Furthermore, we investigate the relationship between economic performance and two other potentially confounding factors: the production type (PT) and the farm size measured in LU ($Size$).

Third, we investigate the relationship between economic performance and animal welfare by using ordinary least squares (OLS) regression, which—in contrast to the correlation analysis—can control for other confounding factors when investigating the effect of one variable on another. The dependent variable is the same indicator of economic performance that we used in the correlation analysis: the gross margin per LU. In order to avoid problems due to high multicollinearity, we only use three out of the five previously used indicators of animal welfare as explanatory variables in the regression analysis: the total number of violations of the animal welfare legislation ($TotNViol$) and two dummy variables, $AnyRooting$ and $AnySick$, that indicate violations of specific parts of the animal welfare legislation. We also include the production type (PT) and farm size ($Size$) as potentially confounding factors in our analysis.[9] As the effect of the animal welfare indicators on the economic performance may depend on the production type, we include

[9] We considered including two additional confounding factors: the year of establishment of the farm and the farmer's age as proxies for the farmer's experience. However, as these variables were individually

interaction terms between the dummy variables for the production type and the indicators of animal welfare as additional explanatory variables. This results in the following model specification:

$$\begin{aligned} GM_i = {} & \alpha_0 + \alpha_1\, TotNViol_i + \alpha_2\, AnyRooting_i + \alpha_3\, AnySick_i \\ & + \alpha_4\, Size_i + \sum_{j=1}^{3} \alpha_{4+j}\, PT_{ji} + \sum_{j=1}^{3} \alpha_{7+j}\, PT_{ji}\, TotNViol_i \\ & + \sum_{j=1}^{3} \alpha_{10+j}\, PT_{ji}\, AnyRooting_i + \sum_{j=1}^{3} \alpha_{13+j}\, PT_{ji}\, AnySick_i + \varepsilon_i, \end{aligned} \tag{1}$$

where $\alpha_j; j = 0, \ldots, 16$ are parameters to be estimated, subscript i indicates the farm, ε_i is a noise term that accounts for the effects of non-observed variables (e.g. management), and PT_{1i}, PT_{2i}, and PT_{3i} are dummy variables that have the value one for specialised slaughter pig producers, farms that raise piglets and fatten slaughter pigs, and producers with sows and piglets, respectively, and are zero otherwise.

Finally, we use the stochastic frontier framework (Aigner, Lovell and Schmidt, 1977; Meeusen and van den Broeck, 1977) to investigate how violations of the animal welfare legislation are related to technical efficiency. As our production model needs to account for more than one output (most Danish pig farms produce other outputs, particularly from arable farming), we use the multiple-output generalisation of a frontier production function: the output distance function (Shephard, 1970). Given that our model includes six inputs and two outputs and our cross-sectional data set only has a rather small number of observations, we use the Cobb-Douglas functional form, which is more parsimonious in parameters than more flexible functional forms such as the Translog functional form. As 10 farms in our dataset do not use agricultural land, we use the extension of the Cobb-Douglas specification suggested by Battese (1997) that can handle zero values in input quantities. This results in the following specification of the output distance function:

$$\begin{aligned} -\log(y_{1i}) = {} & \beta_0 + \theta_2 \log(y_{2i}/y_{1i}) + \beta_1 \log(x_{1i}^*) + \sum_{j=2}^{6} \beta_j \log(x_{ji}) \\ & + \phi_0 D_{1i} + \sum_{j=1}^{3} \phi_j PT_{ji} + u_i + v_i, \end{aligned} \tag{2}$$

where θ_2, $\beta_j; j = 0, \ldots, 6$, and $\phi_j; j = 0, 1, 2, 3$ are parameters to be estimated, subscript i indicates the farm, y_{1i} and y_{2i} are the two output quantities, x_{1i} is the input quantity of agricultural land, $x_{2i}, \ldots, x_{6i}$ are the other five input quantities, D_{1i} is a dummy variable that takes the value of 1 if x_{1i} is zero and zero otherwise, $x_{1i}^* = \max(x_{1i}, D_{1i})$, $v_i \sim N(0, \sigma_v^2)$ is a random noise term that follows a normal distribution with zero mean and variance σ_v^2,

and jointly insignificant in all estimated and tested model specifications, and had missing values for 5 observations, we decided not to include them in our final analysis.

and $u_i \sim N^+(\mu_i, \sigma_u^2)$ is an unobserved non-negative term that accounts for technical inefficiency and follows a truncated normal distribution with location parameter μ_i and scale parameter σ_u. According to our elaborations above, technical (in)efficiency may be related to animal welfare and other confounding factors. In order to take this into account, we use the same model specification for the location parameter of the technical inefficiency term, μ_i, as we use for the gross margin per LU in our linear regression model (1):

$$\begin{aligned}\mu_i = {} & \delta_0 + \delta_1 \, TotNViol_i + \delta_2 \, AnyRooting_i + \delta_3 \, AnySick_i \\ & + \delta_4 \, Size_i + \sum_{j=1}^{3} \delta_{4+j} \, PT_{ji} + \sum_{j=1}^{3} \delta_{7+j} \, PT_{ji} \, TotNViol_i \\ & + \sum_{j=1}^{3} \delta_{10+j} \, PT_{ji} \, AnyRooting_i + \sum_{j=1}^{3} \delta_{13+j} \, PT_{ji} \, AnySick_i.\end{aligned} \tag{3}$$

where $\delta_j; j = 0, \ldots, 16$, are parameters to be estimated. We follow Battese and Coelli (1995) and jointly estimate the stochastic frontier output distance function (2) and the inefficiency effects model (3) by the maximum likelihood method, which gives consistent estimates of all model parameters. Finally, we use the method proposed by Olsen and Henningsen (2011) to obtain the marginal effects of the determinants of technical efficiency.

4 Results

In this section, we present the results of the tests for non-random sample selection, the results of the correlation and regression analyses, and the results of the stochastic frontier output distance function. All estimations and calculations were conducted within the statistical software environment "R" (R Core Team, 2014) using the add-on package "frontier" (Coelli and Henningsen, 2013) for stochastic frontier analysis.

4.1 Test for non-random sample selection

Table 2 presents the results of the tests for differences between the herds that are included in our analysis and the herds that had to be excluded from the analysis because of the non-availability of economic data. These tests indicate that the removal of slightly more than half (54%) of the herds due to non-availability of economic data only biases the sample regarding the herd size of integrated pig producers: herds of integrated pig producers that are included in our analysis are on average 23% larger (in terms of LU) than herds of integrated pig producers that had to be removed from our analysis. In contrast, the removal of herds with unavailable economic data does not significantly affect the average herd size of slaughter pig producers, the average herd size of the entire sample, the distribution of the production types, or the distribution of any of the animal welfare indicators.

Hence, in general, the removal of herds with unavailable economic data does not markedly bias our sample.

Table 2: Tests for non-random sample selection

	Production type	Randomly sampled herds	Analysed herds
Number of herds	all types	299	139
Production Type [%]	integrated	30.4	26.6
	slaughter pigs	45.5	45.3
	other types	24.1	28.1
Size [number of livestock units]	all types	65.0	71.6
	integrated	104.7	128.4**
	slaughter pigs	32.4	33.9
Total violations [number]	all types	2.3	2.4
	integrated	3.4	4.0
	slaughter pigs	1.4	1.1
Any violation [%]	all types	50.2	51.8
	integrated	49.5	56.8
	slaughter pigs	42.6	36.5
AnyRooting [%]	all types	24.1	25.9
	integrated	23.1	32.4
	slaughter pigs	21.3	19.0
AnySick [%]	all types	33.4	34.5
	integrated	29.7	35.1
	slaughter pigs	30.9	27.0
Number of farms	all types	292	135

Note: the values of the continuous variables present averages, while the values of categorical variables present proportions (in percent). Asterisks indicate significance levels of Welch's two-sample t-test (for continuous variables) and Fisher's exact test (for categorical variables), where: *** = 0.01, ** = 0.05, * = 0.1.

4.2 Analysis of correlation

Before analysing the relationship between animal welfare and economic performance, we investigate how compliance with animal welfare legislation is related to the production type and the farm size, which provides useful background knowledge for our subsequent analyses. Some of our animal welfare indicators significantly differ between production types. For instance, integrated pig producers violate on average many more animal welfare regulations than specialised slaughter pig producers (see, e.g., Table 2). This does not necessarily mean that integrated pig producers care less about animal welfare than specialised slaughter pig producers because integrated pig producers have to obey many more animal welfare regulations than specialised slaughter pig producers and, thus, can potentially violate many more of these regulations than specialised slaughter pig producers. In contrast, we do not find any significant relationship between animal welfare and farm size, no matter which production type we consider or which animal welfare indicator we use.[10]

[10] No relationship is significant at the 5% level. The relationship between the provision of rooting and manipulable materials and the size of integrated pig producers is the only relationship that is statistically significant at the 10% level (average size of integrated pig producers who obey all these regulations: 227 LU; average size of integrated pig producers who violate at least one of these regulation: 171 LU; t-value: 1.71; P-value = 0.097).

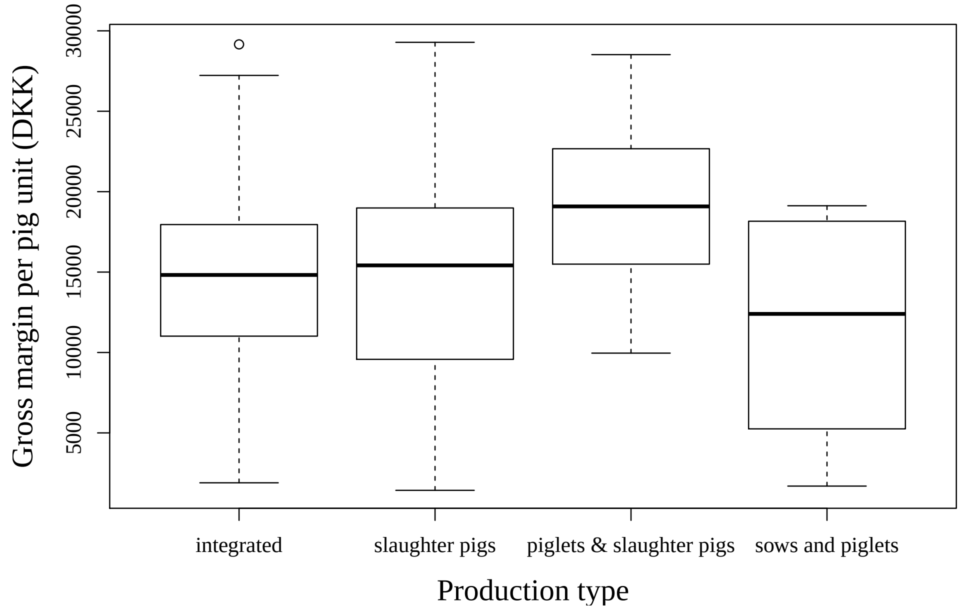


Figure 3: Gross margin per LU (DKK) and production types

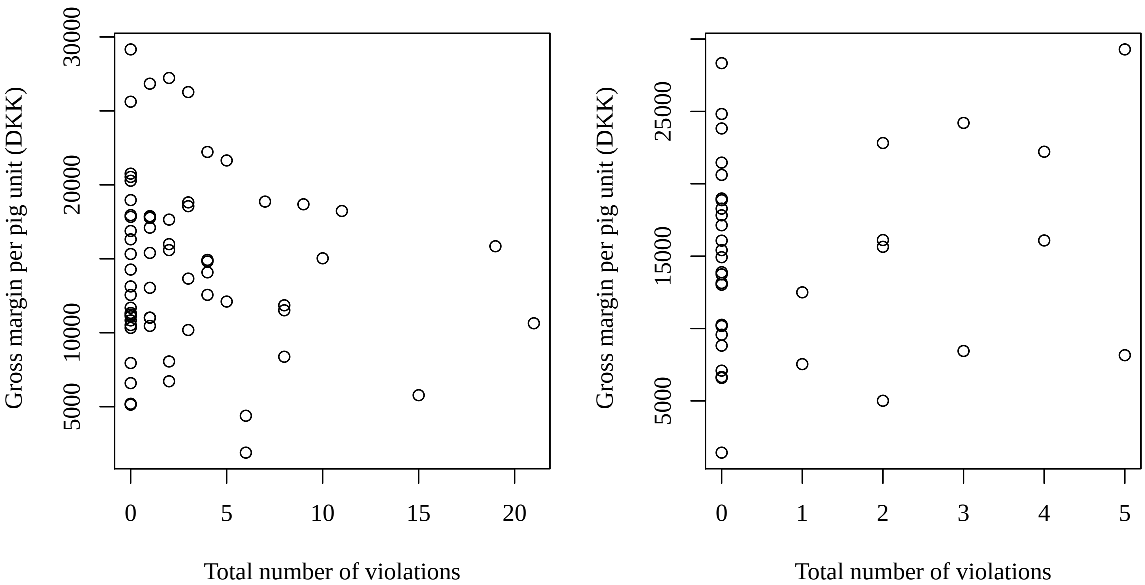
Figure 3 illustrates the variation in the gross margin per LU for four different types of pig production. This figure as well as statistical tests indicate that integrated pig producers, specialised slaughter pig producers, and producers with sows and piglets have on average about the same gross margin per LU, while farms that raise piglets and fatten slaughter pigs have on average a significantly higher gross margin per LU than the other three production types. Figure 3 also illustrates that the gross margin per LU varies considerably within each production type. Statistical tests indicate that there is no significant correlation between gross margin per LU and the size of the pig farm (measured in total number of LU) for any of the analysed groups of pig producers (e.g. t-value: 1.58, P-value: 0.118 for integrated pig producers; t-value: 0.16, P-value: 0.875 for specialised slaughter pig producers)[11] so that other factors than production type and farm size, e.g. management, seem to have a considerable effect on the gross margin.

As the gross margin per LU differs between some of the production types (see Figure 3) and the number of violations of the animal welfare legislation differs considerably between production types (see Table 2), we analyse the correlation between gross margin and different measures of animal welfare separately for each production type.

Figure 4 visualises the relationship between gross margin per LU and the total number of violations of the animal welfare legislation for the two largest groups of pig producers: integrated pig producers and specialised slaughter pig producers. We do not find any

[11] Although other studies (e.g. Rasmussen, 2010; Olsen and Henningsen, 2011) found increasing returns to scale in Danish pig production, it is not surprising that there is no significant correlation between gross margin per LU and the size of the pig farm because the advantages of large pig farms are primarily due to higher labour and capital productivity and the gross margin disregards these two inputs. In contrast, the estimation results of our output distance function, which takes into account all inputs, indicate increasing returns to scale (see Section 4.4).

significant correlation between gross margin per LU and the total number of violations of animal welfare legislation (t-value: -1.05, P-value: 0.300 for integrated pig producers; t-value: 1.02, P-value: 0.317 for specialised slaughter pig producers).



(a) integrated pig producers

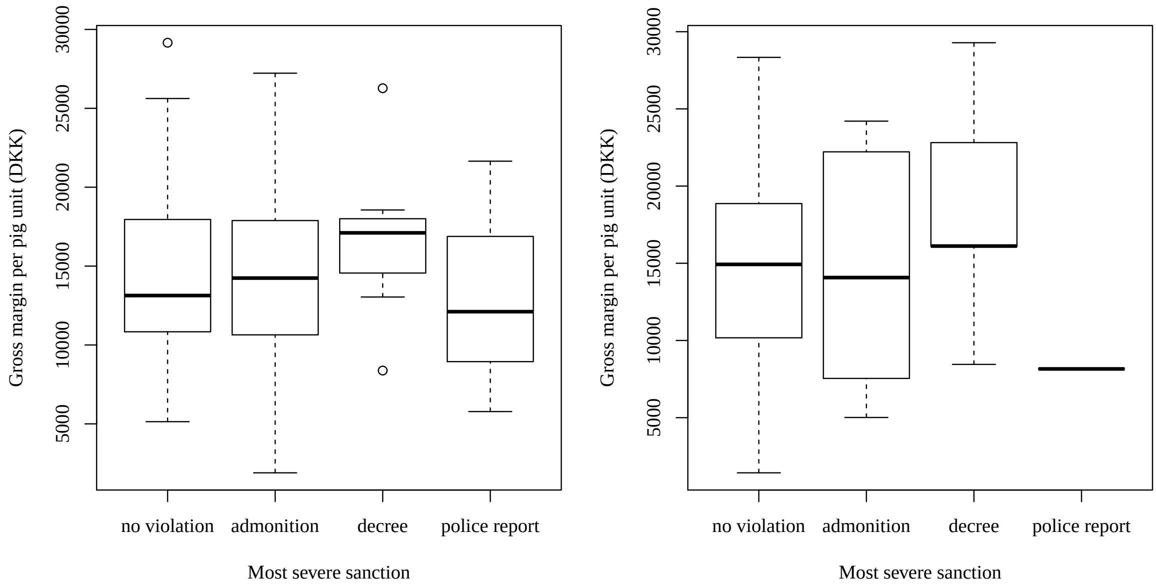
(b) specialised slaughter pig producers

Figure 4: Gross margin per LU (DKK) and the total number of violations for integrated pig producers and specialized slaughter pig producers

Figure 5 investigates the relationship between animal welfare and economic performance using the most severe sanction for violations of the animal welfare legislation as an indicator of animal welfare. One-way ANOVA and Tukey's (1949) Honest Significant Differences (HSD) test of multiple (pairwise) comparisons reveal that the relationship between the gross margin per LU and the severity of the sanction is statistically insignificant at any reasonable significance level both for integrated pig producers and for specialised slaughter pig producers. However, the power of the above-mentioned tests is not very high because there are only few observations in some of the categories of most severe sanctions.[12]

In order to increase the power of our graphical analysis and the statistical tests, we use an even simpler indicator of animal welfare: whether a farm complies with all animal welfare regulations or violates at least one regulation. Figure 6 compares the gross margins per LU of farms that comply with all animal welfare regulations with the gross margins of farms that violate at least one regulation. The distributions of the gross margins per LU are very similar for the two groups of farms. Accordingly, t-tests indicate that the average gross margins per LU do not significantly differ between farms that comply with all animal welfare regulations and farms that violate at least one regulation (t-value: -0.20, P-value:

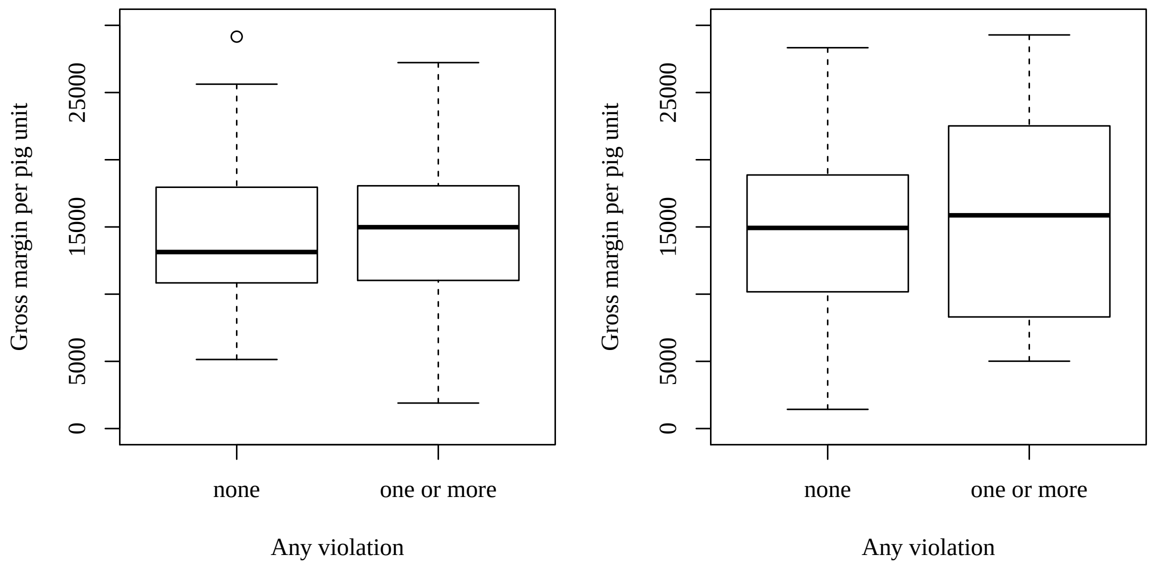
[12] For instance, only three integrated pig producers and one specialised slaughter pig producer were reported to the police.



(a) integrated pig producers (b) specialised slaughter pig producers

Figure 5: Gross margin per LU (DKK) and the most severe sanction for integrated pig producers and specialized slaughter pig producers

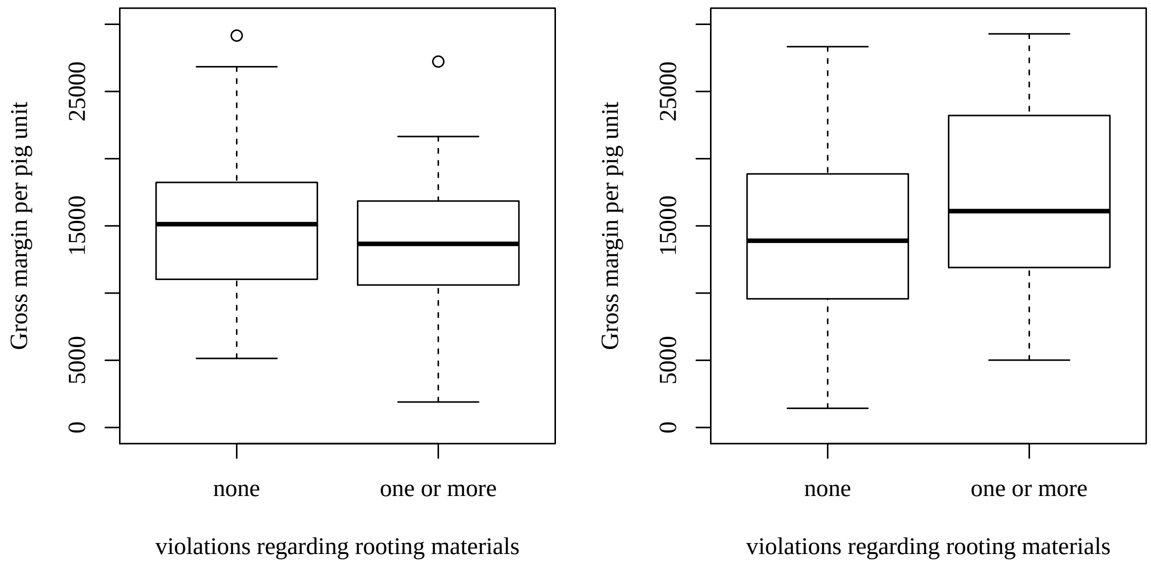
0.841 for integrated pig producers; t-value: -0.32, P-value: 0.750 for specialised slaughter pig producers).



(a) integrated pig producers (b) specialized slaughter pig producers

Figure 6: Gross margin per LU (DKK) and violation of any animal welfare regulation for integrated pig producers and specialized slaughter pig producers

As the relation between violations of the animal welfare regulation and the gross margins per LU may depend on the part of the animal welfare regulation that has been violated (or not), we separately look at violations regarding rooting and manipulable materials and violations regarding the treatment of sick animals. These relationships are visualised by Figures 7 and 8, respectively. Both for integrated pig producers and specialised slaughter pig producers, the average gross margin per LU does not differ significantly between farms that comply with all regulations regarding rooting and manipulable materials and farms that violate at least one of these regulations (t-value: 0.99, P-value: 0.331 for integrated pig producers; t-value: -0.82, P-value: 0.433 for specialised slaughter pig producers). Similarly, the gross margin per LU does not differ significantly between farms that comply with all regulations regarding the treatment of sick animals and farms that violate at least one of these regulations (t-value: -0.99, P-value: 0.327 for integrated pig producers; t-value: -0.76, P-value: 0.463 for specialised slaughter pig producers).



(a) integrated pig producers (b) specialized slaughter pig producers

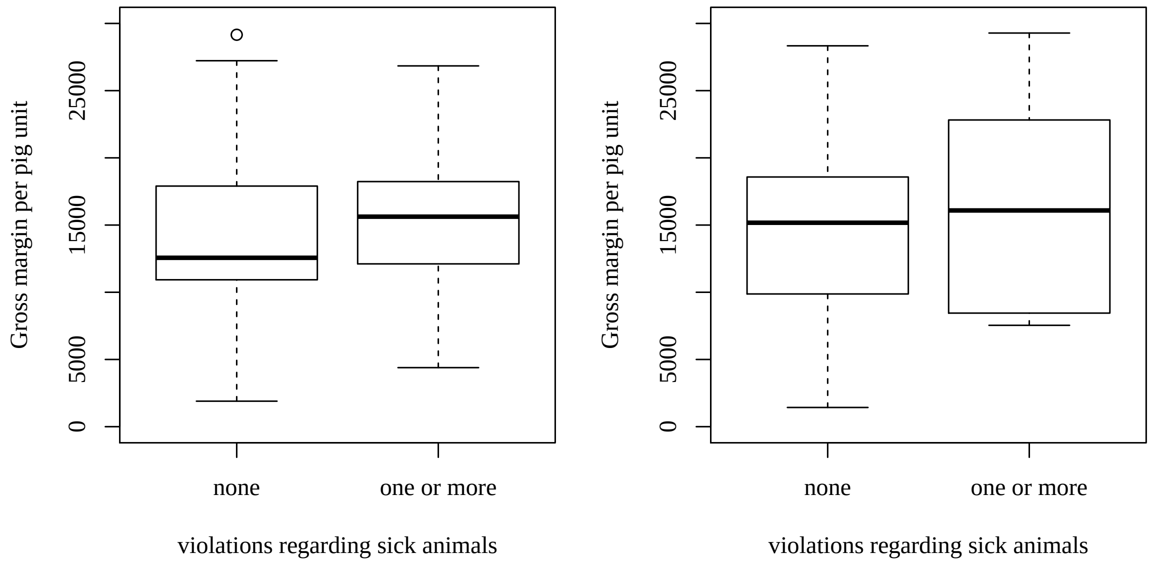
Figure 7: Gross margin per LU (DKK) and violations regarding rooting and manipulable materials for integrated pig producers and specialized slaughter pig producers

In summary, no matter which indicator of animal welfare we use, we do not find any significant relation between farms' compliance with animal welfare legislations and the average gross margin per LU.

4.3 Regression analysis

This section presents the results of our regression analysis based on the model specified in equation (1). Descriptive statistics of the variables used in the regression model are presented in Table 3.

The results of the linear regression model are presented in Table 4. Columns two to four of this table present the estimation results of the (general) regression model specified in equation (1). Most of the estimated parameters are not even statistically significant at the 10% significance level. However, the F-statistic indicates that all estimated parameters



(a) integrated pig producers (b) specialized slaughter pig producers

Figure 8: Gross margin per LU (DKK) and violations regarding sick animals for integrated pig producers and specialized slaughter pig producers

Table 3: Descriptive statistics of the variables used in linear regression of gross margin

	Unit	Mean	S.D.
Gross margin per LU	Thousand DKK	15137.4	6319.3
Size	Pig units	148.4	122.4
TotNViol	total number of violations	2.4	4.1
AnyRooting	Dummy variable	0.27	
AnySick	Dummy variable	0.35	
Production type (integrated) - PT0	Dummy variable	0.48	
Production type (slaughter pigs) - PT1	Dummy variable	0.27	
Production type (piglets & slaughter pigs) - PT2	Dummy variable	0.15	
Production type (sows & piglets) - PT3	Dummy variable	0.10	

together are statistically significant at the 5% significance level. Columns five to seven of Table 4 present the results of a restricted model, in which we have removed all interaction terms. A likelihood ratio test indicates that fit of the restricted model is not significantly worse than the fit of the general model (test statistic: 12.78, P-value: 0.385). The estimation results of the restricted model indicate that farms that specialise in raising piglets and fattening slaughter pigs have *ceteris paribus* a significantly higher gross margin per LU than the other production types.[13] The most interesting result is that more

[13] The coefficient of the dummy variable for the production type "piglets & slaughter pigs" indicates that this production type has *ceteris paribus* a significantly higher gross margin per LU than integrated pig producers. Two further tests indicate that the coefficient of the dummy variable for the production type "piglets & slaughter pigs" is significantly larger than the coefficients of the dummy variables for the other two production types. Hence, we can conclude that farms of the production type "piglets & slaughter pigs" have *ceteris paribus* a significantly higher gross margin per LU than any of the other three production types. This has already been suggested (although not in a *ceteris paribus* framework) by Figure 3.

violations of the animal welfare legislation are associated with lower gross margins. On average, each violation of the animal welfare legislation corresponds to a reduction in the gross margin per LU of around 400 DKK, whereas the violated part of the animal welfare legislation (i.e. the requirements regarding rooting and manipulable materials and the treatment of sick animals) seems to be irrelevant.

Table 4: Results of linear regression of gross margin

	General model			Restricted model		
	Estimate	Std. Error	P-value	Estimate	Std. Error	P-value
(Intercept)	12800.52	1609.16	0.000	13613.84	1411.96	0.000
TotNViol	-255.65	221.02	0.250	-413.51	169.01	0.016
AnyRooting	-115.90	1897.64	0.951	1064.57	1314.10	0.419
AnySick	2309.54	1790.46	0.200	1811.45	1320.41	0.173
Size	8.20	5.52	0.140	5.89	5.23	0.262
PT1 (only slaughter)	1153.52	1840.10	0.532	884.79	1504.43	0.557
PT2 (piglets & slaughter)	6077.29	2368.00	0.012	4811.64	1667.63	0.005
PT3 (sows & piglets)	264.88	2309.58	0.909	-2370.38	1868.97	0.207
TotNViol*PT1	312.57	2512.94	0.901			
TotNViol*PT2	423.89	749.82	0.573			
TotNViol*PT3	152.36	518.69	0.769			
AnyRooting*PT1	1615.36	6453.23	0.803			
AnyRooting*PT2	-901.24	4172.89	0.829			
AnyRooting*PT3	-2381.17	6830.82	0.728			
AnySick*PT1	-936.11	5728.64	0.870			
AnySick*PT2	-3488.43	3925.19	0.376			
AnySick*PT3	-13568.34	7685.61	0.080			
R^2 (Adjusted R^2)	0.199 (0.091)			0.146 (0.099)		
F-statistic	1.835 (16, 118), P-value: 0.034			3.101 (7, 127), P-value: 0.005		

However, the low (adjusted) R^2 values of both the general and the restricted linear regression model indicate that these models have a rather low explanatory power. This means that the production type, the farm size (measured in LU), and the violations of the animal welfare legislation only explain a small fraction of the large variation of the economic performance (measured by the gross margin per LU). Hence, there must be other factors, e.g. management, that have a much greater effect on economic performance.

4.4 Technical efficiency analysis

Summary descriptive statistics of the input and output variables that are used in the technical efficiency analysis are presented in Table 5, whereas the results of the stochastic frontier estimation are presented in Table 6.

The upper part of Table 6 presents the estimation results of the output distance frontier function (equation 2), while the lower part of the table presents the estimation results of the inefficiency model (equation 3). Columns two to four of Table 6 present the estimation results of the (general) model specified in equations (2) and (3). Columns five to seven present the estimation results of a restricted model, in which we have removed all interaction terms from the explanatory variables of the inefficiency model. A likelihood

Table 5: Descriptive statistics of the variables used to estimate the output distance function

	Variable	Unit	Mean	S.D.
Animal output	Y_1	Thousand DKK	7207.61	5404.87
Other outputs	Y_2	Thousand DKK	1809.71	1429.66
Land	X_1	Hectares	183.24	136.43
Feed	X_2	Thousand DKK	4448.47	3184.97
Interm. pig input	X_3	Thousand DKK	438.40	448.54
Other interm. inputs	X_4	Thousand DKK	1315.14	822.12
Labor	X_5	Hours	5305.03	4095.01
Capital	X_6	Thousand DKK	4284.84	3459.60

Table 6: Results of the output distance function

	General model			Restricted model		
	Estimate	Std. Error	P-value	Estimate	Std. Error	P-value
Frontier model:						
(Intercept)	-12.65	69.14	0.855	-0.19	0.06	0.002
Animal output	0.87			0.88		
Crop output	0.13	0.02	0.000	0.12	0.02	0.000
Land	-0.04	0.03	0.188	-0.02	0.03	0.448
Feed	-0.71	0.04	0.000	-0.72	0.04	0.000
Intermediate pig input	-0.11	0.02	0.000	-0.11	0.02	0.000
Other intermediate inputs	-0.07	0.04	0.111	-0.10	0.04	0.016
Labor	-0.00	0.02	0.883	-0.01	0.02	0.799
Capital	-0.10	0.02	0.000	-0.07	0.02	0.000
D_1	0.12	0.06	0.038	0.11	0.05	0.037
PT1	12.49	69.14	0.857	0.04	0.08	0.610
PT2	12.62	69.15	0.855	0.18	0.07	0.009
PT3	12.48	69.14	0.857	-0.05	0.10	0.600
Inefficiency equation:						
(Intercept)	12.64	69.15	0.855	0.14	0.10	0.144
TotNViol	0.00	0.00	0.334	0.01	0.00	0.010
AnyRooting	-0.02	0.04	0.576	-0.09	0.05	0.086
AnySick	-0.05	0.04	0.125	-0.05	0.04	0.218
Size	0.00	0.00	0.566	0.00	0.00	0.466
PT1	-12.52	69.13	0.856	-0.06	0.12	0.592
PT2	-118.84	655.46	0.856	-24.27	7.49	0.001
PT3	-12.60	69.13	0.855	0.05	0.13	0.716
PT1*TotNViol	0.05	0.07	0.473			
PT2*TotNViols	-0.08	0.10	0.411			
PT3*TotNViol	-0.00	0.01	0.639			
PT1*AnyRooting	-0.17	0.18	0.354			
PT2*AnyRooting	105.98	586.15	0.857			
PT3*AnyRooting	-0.30	0.50	0.550			
PT1*AnySick	-0.05	0.16	0.770			
PT2*AnySick	0.44	0.70	0.528			
PT3*AnySick	0.44	0.17	0.010			
σ^2	0.01	0.00	0.000	0.02	0.00	0.000
γ	0.86	0.07	0.000	0.87	0.06	0.000
mean efficiency		0.47			0.87	
log-likelihood value		131.17			122.52	

ratio test does not clearly indicate whether the fit of the restricted model is significantly worse than the fit of the general model (test statistic: 17.30; P-value: 0.044). Due to a rather limited number of observations and the many considerably correlated explanatory variables, the general model is likely over-parameterised. Therefore, we focus on the results of the restricted model.

Likelihood ratio tests clearly indicate that the analysed production is characterised by significant technical inefficiency, i.e. they reject the ordinary least squares (OLS) estimation in favour of the estimation as stochastic frontier model (test statistic: 44.16, P-value: 0.0003 for the general model; test statistic: 26.85, P-value: 0.0008 for the restricted model). The frontier part of the estimated model can be used to investigate the (frontier) production technology of the analysed farms. The parameters $\beta_j; j = 1, \ldots, 6$ of the Cobb-Douglas stochastic output distance function are equal to the distance elasticities of the inputs, i.e. if the quantity of input j is increased by 1%, the aggregate output quantity increases *ceteris paribus* by -β_j%. For instance, increasing (decreasing) the feed input by 1% would increase (decrease) the aggregate output by around 0.72%. We found that the distance elasticities of all outputs are positive, while the distance elasticities of all inputs are negative (although the estimated parameters of land input and labour input are not significantly different from zero). This means that the estimated output distance function globally fulfils the monotonicity conditions derived from microeconomic theory, which is a prerequisite for (reasonably) analysing technical efficiency (Henningsen and Henning, 2009). In the case of an output distance function, the elasticity of scale is equal to the negative sum over the distance elasticities of all inputs (Färe and Primont, 1995). The elasticity of scale of our estimated output distance function is around 1.03, which indicates that the analysed production technology exhibits slightly increasing returns to scale. This estimate is generally in line with earlier studies of Danish pig producers. For instance, Rasmussen (2010) found that the elasticity of scale of Danish pig farms declined from 1.25 in 1986 to 1.13 in 2006 and Olsen and Henningsen (2011) found the elasticity of scale to be 1.06 on average during the years 1996-2008.

The estimated parameters of the explanatory variables in the inefficiency equation, $\delta_j; j = 1, \ldots, 16$, indicate the relationship between these variables and the inefficiency term u. Thus, a positive (negative) parameter indicates a positive (negative) relationship between the respective variable and technical *inefficiency* and, thus, a negative (positive) relationship between the respective variable and technical *efficiency*. For instance, the statistically significant and positive parameter of the total number of violations (TotNViol) indicates that a larger number of violations of the animal welfare regulations is associated with higher technical inefficiency and, thus, lower technical efficiency. Marginal effects calculated with the formula given in Olsen and Henningsen (2011) indicate that on average the violation of one additional animal welfare regulation is associated with a 0.1 percentage points lower technical efficiency. Thus, a farm that violates 10 animal welfare regulations produces *ceteris paribus* at least 1% less output than a farm that does not violate any animal welfare regulations.

The estimated parameter of the AnyRooting animal welfare indicator is only significant at the 10% significance level. Its negative value indicates that a violation of the requirements regarding rooting and manipulable materials is *ceteris paribus* (e.g. having the same number of total violations) associated with lower technical inefficiency and thus, higher technical efficiency. Marginal effects indicate that on average a farm that violates animal welfare regulations regarding rooting and manipulable materials achieves *ceteris paribus* a 0.7 percentage points higher technical efficiency and, thus, at least 0.7% more output than a farm that violates other parts of the animal welfare regulations. This may not be surprising since the provision of rooting and manipulable materials requires additional inputs (e.g. the material and additional labour) that obviously do not generate a corresponding amount of output so that pig farmers who do not provide sufficient rooting and manipulable materials have *ceteris paribus* a higher technical efficiency than farmers who violate other animal welfare regulations.[14]

5 Discussion

We find large variations in economic performance indicators and indicators of compliance with the animal welfare legislation, while the relationships between these two groups of indicators are generally rather weak. Our regression analysis and efficiency analysis indicate that the number of violations of animal welfare regulations is slightly negatively associated with economic performance, which indicates a weak positive relationship between animal welfare and economic performance. While other empirical studies about the relationship between animal welfare and economic performance mostly analyse dairy cows and use health indicators as animal welfare indicators, our study analyses the pig sector and uses compliance with animal welfare regulations as animal welfare indicators. In spite of these differences, the results of our study are generally in line with the results of earlier studies that either find no or no clear relationship between animal welfare and economic performance (Lawson et al., 2004a,b) or a slightly positive relationship (Jensen et al., 2008; Barnes et al., 2011; Stott et al., 2012).

The limitations of our research are mainly due to the nature of our data set, which is rather unique because it combines economic indicators with information from unannounced animal welfare inspections of randomly sampled pig herds, although it also has some limitations. First, while the economic data represent an entire year, animal welfare was only observed at one specific time of the year, whereas the outcome of the animal welfare inspection may have been different if it had been conducted on another day of

[14] In the inefficiency part of the general model, only one of the 12 parameters that are related to animal welfare is statistical significant. However, a likelihood ratio test indicates that all animal welfare indicators and their interaction terms are jointly significant (test statistic: 24.29; P-value: 0.019).

the year. Second, our animal welfare indicators focus on negative deviations from the legally required minimum animal welfare level, while they ignore all aspects that give a higher level of animal welfare than required by the animal welfare regulations. Third, many farms in our data set have more than one herd, but in most cases, we only have animal welfare data for one of the herds. Fourth, our study is not based on experimental data, but on observational data so that we cannot analyse causal effects of animal welfare on economic performance, but just the relationship between animal welfare and economic performance.

6 Conclusions

Many consumers are worried that the welfare of farm animals is too low, particularly on large "industrial" and "profit-oriented" livestock farms. On the other hand, many livestock farmers are worried that stricter animal welfare regulations will decrease their economic performance and, thus, their competitiveness. Due to this dissent, animal welfare has become one of the key aspects in the public debate related to agricultural production, particularly in developed countries. Our results do not substantiate consumers' worries as they clearly indicate that large farms and farms with high economic performance do not have a lower level of animal welfare than smaller farms or farms with lower economic performance.

Our study cannot analyse the effect of tightening the current animal welfare regulations as demanded by several consumers and NGOs because the same—currently effective—animal welfare regulations apply to all herds in our data set. However, given our theoretical model illustrated in Figure 2, our results suggest that the currently legally required minimum level of animal welfare for pig production in Denmark (D in Figure 2) is not significantly above the economic performance maximising level of animal welfare (B) so that the economic performance at the currently legally required minimum level of animal welfare (P_D) is not significantly above the maximum economic performance (P_B) because otherwise we would likely have found that farms that violate some animal welfare regulations would have a higher economic performance than farms that obey all animal welfare regulations. Furthermore, given the large variations between farms both in terms of economic performance indicators and in terms of animal welfare indicators, but the very weak relationship between these two indicators, our results indicate that the management (e.g. skills, aims, motivations) has a major influence on both economic performance and animal welfare. Indeed many farm managers manage to obey all animal welfare regulations and at the same time achieve a high economic performance.

Given the high relevance of animal welfare in the public debate about "industrialised" large-scale livestock production and the existence of very few empirical studies about the relationship between animal welfare and the economic performance of livestock farms, we expect that our study will inspire other researchers and will spur further research in this area. As discussed in Section 5, our study still has many limitations that need to be overcome in future studies. For instance, repeated animal welfare inspections—within a year and/or in subsequent years—could give a more precise assessment of animal welfare and would facilitate an assessment of the development of animal welfare over time. It could also be interesting to investigate the extent to which our results can be generalised to other sectors (e.g. poultry) or to other countries (e.g. countries with different legal requirements for the welfare of farm animals). Furthermore, the use of different measures of animal welfare, e.g. taking into account aspects that give a higher animal welfare than legally required, outcome-based animal welfare measures, and/or using "big data" collected by sensors that are more and more frequently used in "precision livestock farming," is also a promising path for future research. Finally, impact assessment methods in combination with field experiments or natural experiments could be used to investigate causal effects of (measures that affect) animal welfare on economic performance.

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