

Is there any causal effect between animal welfare and farm economic performance? Evidence from Finnish dairy farms

Amer Ait Sidhoum * and Jarkko K. Niemi 

Natural Resources Institute Finland (Luke), Business Economics, Latokartanonkaari 9, FI-00790, Helsinki, Finland

*Corresponding author: Natural Resources Institute Finland (Luke), Business Economics, Latokartanonkaari 9, FI-00790, Helsinki, Finland. E-mail: amer.ait-sidhoum@luke.fi

Received: April 9, 2025. Accepted: October 28, 2025

Abstract

This paper explores the relationship between animal welfare and economic outcomes in agriculture, focusing on whether improvements in animal welfare translate into better farm performance. Specifically, it examines a composite animal welfare index integrating multiple animal-based indicators and its association with milk revenue among Finnish dairy farms over the period 2010–2017. Utilizing multiple econometric approaches, including cross-sectional and panel data regressions, the study reveals a complex and heterogeneous relationship. While a negative association between poorer welfare and milk revenue is evident in cross-sectional estimations, this relationship weakens and generally loses statistical significance once farm-specific fixed effects are included, indicating that much of the association reflects structural or management differences rather than a direct causal effect. The findings underscore the importance of distinguishing correlation from causation when designing and interpreting animal welfare-related policies. Beyond policy relevance, the paper contributes to the limited empirical evidence on causal linkages between animal welfare and farm economic performance.

Keywords: animal welfare, economic outcomes, dairy farms, finland, econometrics

JEL codes: Q12, Q18

1. Introduction

The improvement of animal welfare has become a top priority for the European Union (EU) policy. Various measures have been promoted within the Common Agricultural Policy (CAP) to align it with the goals of the European Green Deal and the Farm to Fork strategy. For instance, the new CAP incorporates four key elements: conditionality, farm advisory services, rural development initiatives, and the new eco-schemes, and these all include measures to improve animal welfare (EU 2021). The effectiveness of these policy initiatives depends on a number of factors such as the design of these initiatives. The profitability of practices is an important driver of adoption in agriculture. While there is a growing interest in investigating the relationship between animal welfare and economic performance of farms, the debate over this relationship is still topical (Tonsor and Wolf 2019;

Ahmed et al. 2020) and its nature is ambiguous (McInerney 2004). It may be due to the complexity of the relationship that the literature provides only limited empirical evidence, and despite the growing debate it remains unclear whether improvements in animal welfare translate into changes in farm economic performance. In particular, the potential causal link between animal welfare levels and farm revenues is still unresolved.

Assessing farm performance with an emphasis on animal welfare is challenging. A variety of indicators, such as those pertaining to anatomy, physiology, behavior, and productivity, have been suggested (see e.g. Gonyou 1986; Broom 1991) as a means of evaluating farm animal welfare. Conversely, Duncan (1993) highlights the need of defining it in terms of the subjective experiences of the animals rather than only their physiological state or other clinical indicators. While many definitions of animal welfare exist, McGlone (2001) pointed out, there is considerable consensus regarding the use of outcome-based indicators, like the frequency of wounds on animals, or resource-based indicators, like stocking density and water availability. Fraser (2003) suggests that because outcome-based indicators are thought to more precisely reflect the experiences of the animals, they have gained popularity. However, resource-based indicators have two major advantages in practical applications. First, farmers have direct control over them (e.g. space allowance per animal), as they are intimately related to farming operations. Controlling outcome-based markers, such as skin alteration levels, is to some extent random, though. Second, it is easier to track and evaluate indicators that are dependent on resources than outcomes.

Many studies have used animal health indicators as a proxy for animal welfare. Examples are reproductive disorders (Lawson et al. 2004), lameness prevalence (Barnes et al. 2011) and mastitis management (Hansson et al. 2011). Recently, several studies have used the Welfare Quality Assessment Protocols to measure animal welfare at the farm level (Stott et al. 2012; Schulte et al. 2018). Economics studies have used either resource-based indicators, such as building costs, rate of culling and veterinary costs (Hansson et al. 2018), or policy-oriented indicators, such as the number of violations of the animal welfare legislation (Henningsen et al. 2018). In the present study, we employ a composite animal welfare index that integrates four animal-based indicators: locomotory disorders, uterine disease, calf mortality, and somatic cell count (SCC).

The choice of these four indicators follows the view that farm animal welfare is best understood as a multidimensional construct rather than proxied by a single outcome (Nielsen et al. 2023). They are widely recognised as central health-based measures of dairy cow welfare, each reflecting pain, discomfort, or impaired physiological functioning, and have been identified by the EFSA Panel on Animal Health and Welfare as among the most informative risk-based indicators of poor dairy welfare (Nielsen et al. 2023). Locomotory and hoof disorders are highly prevalent and strongly impair mobility and quality of life (Reader et al. 2011). Uterine disease is a major reproductive disorder with consequences for both animal welfare and fertility (Galvão, Bicalho, and Jeon 2019). SCC is a routine indicator of udder health, associated with mastitis risk and milk quality (Costa et al. 2020). Calf mortality remains an important welfare proxy, reflecting failures in disease prevention, calving management, and the care of vulnerable animals (Roche et al. 2023).

The literature on the effects of animal welfare and health issues on farm economics has mainly identified statistical associations rather than causal links, possibly reflecting underlying differences in management quality or herd structure. Most of these existing studies report weak but positive relationships between economic performance and animal welfare indicators (Barnes et al. 2011; Stott et al. 2012; Henningsen et al. 2018). For instance, Bell and Wilson (2018) found that improving the fertility and health of cows raises their survival rates, which in turn tend to raise profitability. Villettaz Robichaud et al. (2018) investigated the financial effects of following the proAction Animal Care requirements in Canada and found that individual farms may even benefit from these standards. Similarly, Hansson et al. (2011) and Pérez-Méndez et al. (2020) both reported that technical efficiency improves with

better animal health and lower disease incidence. Specifically, [Hansson et al. \(2011\)](#) found that adopting best-practice farming could reduce costs by nearly 30 per cent, while [Pérez-Méndez et al. \(2020\)](#) reported that a reduction in somatic cell counts (SCC) was associated with nearly a 6 per cent increase in profits. Several other studies support this positive association (e.g. [Dekkers et al. 1996](#); [Huijps et al. 2008](#); [Bruijnjs et al. 2013](#); [van der Voort et al. 2014](#); [Dillon et al. 2015](#); [Skevas and Cabrera 2020](#); [Puerto et al. 2021](#)). However, the direction and magnitude of causality remain uncertain. With few studies using identification strategies suited to causal inference, evidence on whether improving welfare causes better economic outcomes remains scarce.

To the best of our knowledge, only one study has attempted to estimate a causal effect of farm animal welfare effort on the economic performance of Swedish beef farms ([Ahmed et al. 2023](#)). While this study did not focus explicitly on welfare outcomes, it measured ‘animal welfare effort’ through farmers’ management practices, such as grouping of animals, disease and parasite control, housing allowances, cleaning routines, cow—calf contact periods, and provision of pasture. What is still needed to advance this field is a clear understanding of whether causal effects exist. As emphasized in a recent literature review, [af Sandeberg et al. \(2023, pp. 9\)](#) conclude that ‘future research should aim to investigate the causal effect of animal health on farm economic outcomes.’

The objective of this study was to examine the relationship between animal welfare and milk revenues by using empirical data collected from Finnish dairy farms. In the following sections, we provide a detailed explanation of the different empirical approaches we adopt to deepen our understanding of the relationship between animal welfare (proxied here by a composite animal welfare index) and farm economic performance (proxied here by milk revenue).

2. Data

The empirical data used in this study consisted of farm-level annual observations from a sample of Finnish dairy farmers, covering the years 2010–2017. The data were obtained from the databases of ProAgria, a rural advisory organisation in Finland, and Faba, the Finnish Animal Breeding Association. [Table 1](#) provides descriptive information on the parameters used in the analysis.

Data concerning animal health recordings (number of animals observed with clinical symptoms for each disorder per year per farm), number of calves born per farm, and the level of genetic merit of cows in the herd were obtained from Faba. All other data, such as parameters concerning the quality and quantity of milk yield, input use (especially feed), nutrient data, and information on grazing and indoor confinement, were obtained from ProAgria. As both datasets are managed by the same IT service provider, the data were delivered in one batch, ensuring that observations were at the farm-level and anonymous. The data from ProAgria originated from various farm monitoring systems managed by the organization. The observational unit in the analysis was a farm. Therefore, animal health records, for example, represent the number of observed cases of an animal disease per farm each year.

The resulting unbalanced panel data included a total of 51,062 rows of observations (each row representing data for one year and one farm) from 7,966 different farms. This number represents a considerable proportion of Finnish dairy farms, which numbered 10,923 in 2010 and 7,032 in 2017 ([Luke 2024](#)). The average herd size was 36.15 dairy cows per farm. Several econometric models were used to analyze these data, as detailed in the subsequent section. However, a maximum 26,821 observations were available for estimating individual equations, since not all farms had valid data for all parameters of interest. The availability of data varied depending on which advisory services each farm had utilized. Nevertheless, this extensive dataset allowed for accurate measurements that are

Table 1. Description and summary statistics of variables used in the analysis. The data are annual farm-level observations.

| Variable | Unit | Description variable | Mean | S.D. |
|-----------------------------|--|---|----------|--------|
| Milk revenue | Euros/cow/year | Milk income over a 12-month period. | 3,770.15 | 721.62 |
| Animal welfare index | Index | Composite animal welfare index from four indicators: locomotory disorders, uterine disease, calf mortality, and SCC. | ≈ 0 | 1 |
| Calf mortality | Percentage | Calf mortality rate, indicating the rate of death among calves (less than 6 months old). | 7.39 | 6.20 |
| Locomotory disorders | Number of cases observed per year per farm | Hoof and locomotory disorders in cattle. | 0.84 | 4.32 |
| Uterine diseases | Number of cases observed per year per farm | Udder diseases or disorders, including infections or abnormalities affecting the health and function of the cow's udder. | 7.19 | 10.26 |
| Somatic cell count | cells/mL | Measuring the level of somatic cells in milk. | 165.93 | 76.76 |
| Feed saving index | Index | Feed efficiency index, measuring the efficiency of feed utilization by the animals. | 102.31 | 2.57 |
| Dry matter intake | kg/cow | Average feed intake per cow, is measured as kg dry matter per cow, representing the amount of feed consumed by each cow on average. | 20.14 | 2.13 |
| N utilization | Percentage | Nitrogen utilization percentage, indicating the efficiency of nitrogen utilization in the feed by the cows. | 28.71 | 3.06 |
| P utilization | Percentage | Phosphorus utilization percentage, indicating the efficiency of phosphorus utilization in the feed by the cows. | 29.30 | 4.05 |
| Milk urea | mg/dL | Milk urea, measuring the concentration of urea nitrogen in milk. | 28.90 | 4.46 |
| Silage analyses | Number of analyses | How many silage quality analyses have been carried out on the farm in a year. | 5.43 | 7.05 |
| Metabolizable energy intake | Megajoules (MJ) per animal | Metabolizable energy intake by lactating cows, indicating the energy available for growth, reproduction, and milk production. | 10.90 | 0.21 |

Table 1. Continued

| Variable | Unit | Description variable | Mean | S.D. |
|----------------------------------|--|---|-------|-------|
| Total breeding value | Genetic units | Overall breeding value, i.e. the genetic merit of the animals. | -0.35 | 3.43 |
| Expected value of the heifer | Expected progeny difference (EPD) | An index indicating the expected performance or genetic merit of replacement heifers in the herd. | 7.75 | 4.48 |
| Milk fever | Number of cases observed per year per farm | Milk fever is a metabolic disorder caused by insufficient calcium, typically occurring upon calving. | 2.15 | 3.23 |
| Ketosis | Number of cases observed per year per farm | Ketosis or metabolic disorder in cows, characterized by an abnormal increase in ketone bodies in the blood. | 0.53 | 1.32 |
| Dietary disorders | Number of cases observed per year per farm | Feeding-related disorders or disruptions, referring to issues or problems related to the animal's diet. | 1.16 | 3.98 |
| Other diseases | Number of cases observed per year per farm | Other diseases or health conditions, representing a category for miscellaneous or unspecified illnesses. | 5.63 | 15.95 |
| Barn type | Binary (1 = true, 0 not true) | Barn or cow housing type, indicating the type of facility used for keeping the cows. | 0.31 | 0.46 |
| Summer Outdoor/Winter Indoor | Binary (1 = true, 0 not true) | Cows have access to an open outdoor space during the summer and are confined indoors during the winter. | 0.15 | 0.36 |
| Summer Pasture/Winter Indoor | Binary (1 = true, 0 not true) | Cows graze in the summer and are confined indoors in the winter. | 0.62 | 0.49 |
| Summer Pasture/Winter Recreation | Binary (1 = true, 0 not true) | Cows graze in the summer and are let to an outdoor yard in winter. | 0.07 | 0.26 |
| Summer Garden/Winter Indoor | Binary (1 = true, 0 not true) | Cows have access to an outdoor yard in the summer, but are confined indoors in the winter | 0.05 | 0.22 |
| Summer Garden/Winter Outdoor | Binary (1 = true, 0 not true) | Cows have access to an outdoor yard in the summer and are let to an outdoor yard in the winter. | 0.02 | 0.14 |

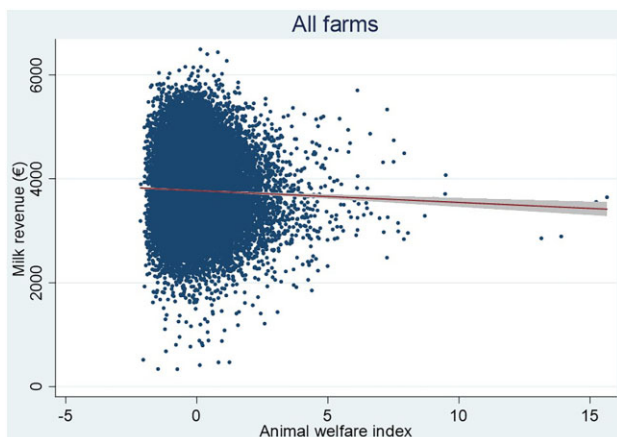


Figure 1. A scatterplot showing the relationship between the animal welfare index and milk revenue, together with a linear trendline that was fitted to the data in the whole dataset.

crucial in determining a causal relationship while controlling for a multitude of co-varying conditions.

To capture farm-level animal welfare in a single measure, we constructed a composite animal welfare index¹ based on four animal-based indicators: locomotory disorders, uterine disease, calf mortality, and somatic cell count (SCC). Each indicator was first standardized to have mean zero and unit variance, to ensure comparability across variables measured on different scales. The standardized indicators were then averaged to form the composite index:

$$AWI_i = \frac{1}{4} \sum_{j=1}^4 Z_{ij}$$

where AWI_i is the animal welfare index for farm i , and Z_{ij} represents the standardized value of indicator j (hoof disease, uterine disease, calf mortality and SCC) for farm i . This approach yields a unidimensional index in which higher values correspond to poorer animal welfare outcomes (since higher scores on the individual indicators indicate higher prevalence of health problems). Using a standardized index ensures that all indicators contribute on an equal scale, preventing measures with larger variances from dominating the index. It also provides a transparent and comparable welfare metric that captures multiple dimensions of animal health within a single measure.

Our analysis centres on two main variables: milk revenue, representing farm economic performance, and the animal welfare index, capturing multidimensional welfare outcomes. Figures 1 and 2 illustrate their relationship across all farms. The scatterplot shows considerable variation, with most observations clustered around the centre of the welfare index. The fitted line indicates a weak negative association, suggesting that farms with poorer welfare scores tend to generate slightly lower milk revenues. Because of endogeneity and confounding effects, this association may not present a causality. A potential explanation could be attributed to omitted variable bias. Both the ‘treatment’ and ‘outcome’ in our study have naturally evolved over the years, influenced by various management practices and, perhaps, affected by environmental, farm management or regulatory factors. Consequently, there are possible differences among the farms that could independently impact the level of animal welfare and milk output. Farms reaching a higher milk yield may be better managed than farms having a lower milk yield, and this may be reflected also in animal

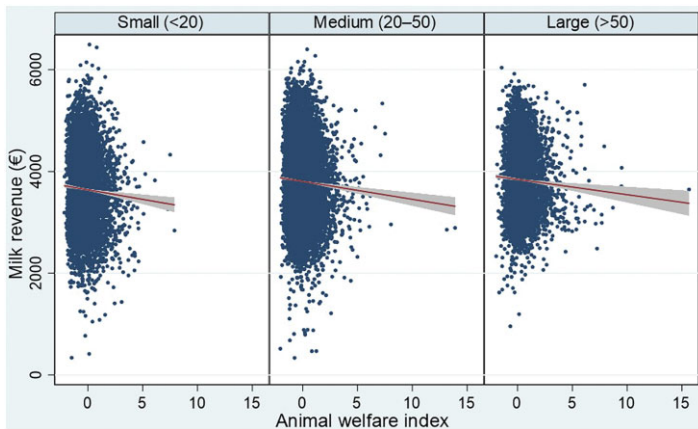


Figure 2. A scatterplot describing the relationship between the animal welfare index and milk revenue by farm size (subsamples of the whole dataset). Fitted lines are linear, showing the association between the animal welfare index and milk revenue separately for large, medium, and small farms.

welfare outcomes more broadly. It is also plausible that higher milk yields are linked to improved herd management and feeding strategies, which can positively influence overall animal health and welfare. These circumstances may reduce the incidence of diseases, enhance reproductive performance, and support better mobility and udder health. Both milk revenues and animal welfare may be affected by good management practices and the level of proficiency of farm management. To account for these confounding factors, the statistical analysis exploits the panel data structure, which controls for farm fixed effects such as management characteristics that remain constant over time.

3. Empirical analysis

As detailed below, a dynamic, results-driven approach, including the estimation of successive econometric models, was used to analyze the data. We begin by examining the association between farms' animal welfare index (AWI_i) and milk revenue (R_i). A regression analysis of the milk revenue on the animal welfare index, incorporating a set of control variables (X_i), was conducted. Three distinct models, each differentiated by the specific variables included in X_i , were estimated. In the first model, particular attention was given to feeding-related factors such as how well feed is utilized, the quantities of feed dry matter consumed, nitrogen and phosphorus utilization, metabolizable energy intake (planned) and urea content of milk, which can be a sign of a balanced protein intake, as well as the intensity of silage quality measurement. The productivity and nutritional state of the dairy cows are directly impacted by these variables, making them crucial (Seppä-Lassila et al. 2016). In the second model, the focus was extended to incorporate variables that represent the dairy herd's genetic characteristics. This had to do with the Total Breeding Value, which shows the genetic potential of the cows for different traits, and the Expected Value of the Heifer, which shows the potential profitability and productivity of the farm's future cows (Dawkins, 2017). In the third model, factors linked to health were incorporated, by including information on the occurrence of milk fever, ketosis, different dietary disorders and other diseases not specifically mentioned. These are just a few of the health problems that can affect dairy cows. (Hogeveen et al. 2019). In these cross-sectional analyses, the estimation specification was as

follows:

$$R_i = \alpha_0 + \alpha_1 AWI_i + \beta X_i + \varepsilon, \quad (1)$$

where the observed milk revenue of farm i is the dependent variable and α_1 is the coefficient of interest, while β and X_i represents the vectors of estimated parameters and control variables, respectively.

Next, the reliability of initial estimates was assessed by using Oster's (2019) methodology. This approach evaluates the sensitivity of estimates to unobserved variables by assessing their sensitivity to observed ones. We started by estimating a comprehensive model that includes all control variables, resulting in the initial coefficient $\hat{\alpha}_{1,F}$. This coefficient was then compared with another derived from a restricted model, labeled $\hat{\alpha}_{1,R}$. By also considering the individual importance of each covariate included, the ratio of the initial coefficient to the difference between the initial and the restricted model coefficients helped determine the degree of unobserved selection (i.e. omitted variable bias) necessary to account for an estimated relationship:

$$\frac{\hat{\delta}_1 = \hat{\alpha}_{1,F}}{\hat{\alpha}_{1,R} - \hat{\alpha}_{1,F}}, \quad (2)$$

where $\hat{\delta}_1$ denotes an estimate indicating the extent to which selection on unobservables, as opposed to observables, would have to be to cancel out the statistical significance of the previously estimated relationships, considering changes in both the coefficients and the R^2 . Furthermore, it was assumed that selection has the same effect on unobservables as it does on observables, and then calculate the value of α_1 in the absence of bias.

Moving forward with the analysis, a panel data analysis was conducted using a two-way fixed-effects regression approach. The empirical model can be formulated as follows:

$$R_{i,t} = \alpha_0 + \alpha_1 AWI_{i,t} + \beta X_{i,t} + \eta_t + \varphi_i \quad (3)$$

where η_t represents year-specific fixed effects and φ_i denotes fixed effects associated with each farm. Through this approach, period-specific shocks and characteristics of farms that are relatively constant over time were controlled. Consequently, this analysis examined the changes in a farm's milk output by comparing the same farm under conditions of higher and lower levels of animal welfare, as captured by the composite animal welfare index.

The results from the fixed-effects regression suggested that there was no direct, causal effect of the animal welfare index on milk output, but instead there is a confounder that spuriously connects the two. To learn more about this confounder, it was tested whether it is linked to any specific on-farm management practices. Specifically, we control for specific housing characteristics into our cross-sectional model, namely the barn type indicating whether the animals are tied or have the freedom of movement and whether they have access to outdoor environments

$$R_i = \alpha_0 + \alpha_1 AWI_i + \alpha_2 B_i + \alpha_3 O_i + \beta X_i + \varepsilon, \quad (4)$$

where B_i represents the barn type and O_i is a categorical variable indicating whether the cows have outdoor access on farm i . Additionally, confidence intervals for parameter estimates were computed and it was examined if they contain values that are economically significant (see Rommel and Weltin 2021 and Ziliak and McCloskey 2004). To further assess the robustness and practical relevance of the results, a Wald test of equality was conducted to compare the baseline model with extended specifications. Together with the examination of the 95 per cent confidence intervals, this allowed us to move beyond statistical significance and evaluate the economic importance of the animal welfare coefficient across models.

Table 2. Association between animal welfare and milk revenue in the cross-sectional analysis.

| | Model (1) | Model (2) | Model (3) |
|------------------------------|----------------------|----------------------|----------------------|
| Animal Welfare index | −0.007*** (0.000) | −0.007*** (0.000) | −0.006*** (0.000) |
| Feed saving index | 0.001*** (0.004) | 0.001** (0.045) | 0.001 (0.102) |
| Dry matter intake | 0.038*** (0.000) | 0.036*** (0.000) | 0.036*** (0.000) |
| N utilization | 0.012*** (0.000) | 0.012*** (0.000) | 0.012*** (0.000) |
| P utilization | 0.002*** (0.000) | 0.001*** (0.000) | 0.001*** (0.000) |
| Milk urea | 0.013*** (0.000) | 0.013*** (0.000) | 0.013*** (0.000) |
| Silage analyses | −0.002*** (0.000) | −0.001*** (0.000) | −0.001*** (0.001) |
| Metabolizable energy intake | 0.114*** (0.000) | 0.104*** (0.000) | 0.104*** (0.000) |
| Total breeding value | | 0.001** (0.023) | 0.001** (0.034) |
| Expected value of the heifer | | 0.003*** (0.000) | 0.003*** (0.000) |
| Milk fever | | | 0.001*** (0.000) |
| Ketosis | | | −0.001 (0.413) |
| Digestive/dietary disorders | | | −0.001*** (0.007) |
| Other diseases | | | −0.000*** (0.000) |
| R-squared | 0.2614 | 0.2592 | 0.2613 |
| Number of observation | 26821 | 24989 | 24989 |

Notes: Dependent variable: milk revenue. Shown are coefficient estimates (p-values) from an ordinary least squares regression with robust standard errors in the presence of heteroskedasticity.

4 Results and discussion

4.1 Cross-sectional analysis

The results of the first cross-sectional analysis examining the statistical association between the animal welfare index and milk revenue (Eq. 1) are presented first. Results in Table 2 show that across all specifications, a consistently negative and highly significant association between the animal welfare index and milk revenue was found (approximately a 0.6–0.7 per cent decrease in milk revenue per unit increase in the index). Hence, the relationship between milk revenues and the animal welfare index remained similar to that illustrated in the scatterplots (Figs. 1 and 2) even after including proxy health indices, feeding and breeding performance data. However, as the estimated regressions' R-squared values were around 0.26, there may be remaining bias due to omitted variables. As explained in the methods section, Oster's (2019) approach was applied to assess concerns regarding omitted variable bias was applied (see Table 3).

Table 3. Oster's (2019) test on selection on observables and unobservables.

| | |
|--|--------|
| The selection on observables is equivalent to the selection on unobservables in terms of the relationship between animal welfare and milk revenue ($\beta \delta = 1$) | -0.005 |
| The relative degree of selection on observables and unobservables that would make the treatment effect zero ($\delta \beta = 0$) | 5.43 |

In the next step of the analysis, we assumed that selection on unobservables was as important as selection on observables ($\delta = 1$). This assumption does not imply that omitted confounders necessarily exist but sets a benchmark given our large vector of observable characteristics. The incorporation of all these control variables explains only partially the estimated relationship between the animal welfare index and milk revenue, indicating that the observed association is not entirely controlled by the observable covariates. The first row of Table 3 shows the adjusted effect of the animal welfare index on milk revenue (for both observed and unobserved variables), while the second row displays the size of the relative selection of observables and unobservables required to produce a zero effect of the animal welfare index on milk revenue. A delta (δ) of 1 means that the selection on observables is equal to the selection on unobservables, whereas a delta (δ) value greater than 1 denotes a stronger influence for unobservables over observables. In our situation, it was found that selection on unobservables would need to have a significantly greater influence than selection on observables in order to eliminate the negative relationship between the animal welfare index and milk revenue.

4.2 Panel analysis results

Overall, there is substantial evidence that farms with higher animal welfare index values (indicating poorer welfare) are associated with less milk output. However, what actually must be known is whether changes in animal welfare levels cause changes in milk yield. Table 4 shows two-way fixed effects regressions that account for any overall year-specific shocks as well as time-invariant characteristics and farm-specific characteristics (such as their farming practices). Regardless of whether the animal welfare index was operationalized as a binary variable that indicates whether it is above or below the median score (Model 2), or with only farms that fall within the top 10 per cent of the index distribution (worst welfare levels; Model 3), no statistically significant relationship between a change in the animal welfare index and a change in milk revenues was found. Whatever the strong cross-sectional relationship in Table 2 is driven by, it is controlled by the panel data specifications in Table 4. Despite the significant cross-sectional association, no evidence that poorer animal welfare (higher index values) has a negative impact on milk revenues was found.

The possibility that there is a significant relationship between changes in the animal welfare index and changes in milk revenue in some farms is a serious concern, but this relationship cannot be seen across the entire sample. This could be due to variations in the underlying factors affecting these two variables across different groups of farms. For example, the relationship might be stronger or more meaningful for farms of a certain economic size, while being weaker or non-existent for others. When dividing the sample into small, medium, and large farms, the results show that the relationship between changes in the animal welfare index and changes in milk revenue is statistically significant only for medium-sized farms, but not for small or large farms (see Table 5). In other words, the presence of a significant negative relationship within the medium-farm subsample suggests that poorer animal welfare (higher index values) is associated with lower milk revenues in this group, whereas for small and large farms, no significant relationship was detected. A possible explanation for this heterogeneity is that medium farms may exhibit greater variation in

Table 4. Association between Animal welfare index and milk revenue. Panel data analysis.

| | Model (1) | Model (2) | Model (3) |
|--------------------------------------|------------------------|------------------------|------------------------|
| Animal Welfare index | -1.07E-03 (0.072) | | |
| Animal Welfare index (Binary) | | -1.30E-03 (0.200) | |
| Animal Welfare index (Top 10% farms) | | | -2.54E-04 (0.814) |
| Feed saving index | -6.82E-04 (0.082) | -6.72E-04 (0.087) | -8.70E-05 (0.956) |
| Dry matter intake | 2.16E-02*** (0.000) | 2.16E-02*** (0.000) | 2.26E-02*** (0.000) |
| N utilization | 4.33E-03*** (0.000) | 4.34E-03*** (0.000) | 4.62E-03*** (0.000) |
| P utilization | 1.73E-03*** (0.000) | 1.73E-03*** (0.000) | 2.52E-03*** (0.000) |
| Milk urea | 1.85E-03*** (0.000) | 1.85E-03*** (0.000) | 1.19E-03* (0.043) |
| Silage analyses | 4.13E-04*** (0.000) | 4.11E-04*** (0.000) | -6.17E-05 (0.754) |
| Metabolizable energy intake | 3.44E-02*** (0.000) | 3.44E-02*** (0.000) | 2.78E-02* (0.029) |
| Total breeding value | 2.20E-04 (0.445) | 2.29E-04 (0.427) | -3.68E-04 (0.742) |
| Expected value of the heifer | -3.56E-05 (0.881) | -3.43E-05 (0.886) | 1.03E-03 (0.153) |
| Milk fever | 7.74E-04*** (0.000) | 7.67E-04*** (0.000) | 6.42E-04 (0.104) |
| Ketosis | 6.78E-04 (0.055) | 6.69E-04 (0.059) | 3.59E-04 (0.637) |
| Digestive/dietary disorders | 2.32E-04 (0.063) | 2.23E-04 (0.073) | -2.15E-05 (0.855) |
| Other diseases | 9.36E-05* (0.020) | 9.09E-05* (0.022) | 3.26E-05 (0.446) |
| R-squared | 0.9223 | 0.9222 | 0.9275 |
| Number of observation | 24028 | 24028 | 2132 |

Notes: Dependent variable: milk revenue. Shown are coefficient estimates (*P*-values) from a two-way fixed-effects (controlling for individual and time effects) panel data regression with robust standard errors in the presence of heteroskedasticity.

management practices and welfare outcomes over time, allowing the model to capture such effects more clearly, while small and large farms may be more homogeneous or constrained by structural factors that limit observable changes.

4.3 Additional robustness and contextual factors

There is a significant difference between our cross-sectional and panel data analysis. The cross-sectional analysis suggests a strong negative association between the animal welfare index and milk revenue. In contrast, the panel data analysis shows no overall link between changes in the animal welfare index and changes in milk revenue, except for medium-sized farms where the relationship remains significant. The most likely explanation for this

Table 5. Estimation results for the panel data analysis by farm size.

| | Farm size categories | | |
|------------------------------|------------------------|------------------------|------------------------|
| | Small | Medium | Large |
| Animal Welfare index | 1.77E-04 (0.887) | -2.90E-03** (0.004) | 1.88E-04 (0.852) |
| Feed saving index | -8.77E-04 (0.373) | 1.30E-04 (0.824) | -6.94E-04 (0.321) |
| Dry matter intake | 2.15E-02*** (0.000) | 2.14E-02*** (0.000) | 1.97E-02*** (0.000) |
| N utilization | 3.45E-03*** (0.000) | 3.77E-03*** (0.000) | 5.49E-03*** (0.000) |
| P utilization | 1.33E-03** (0.009) | 1.53E-03*** (0.000) | 2.21E-03*** (0.000) |
| Milk urea | 1.97E-03*** (0.000) | 1.46E-03** (0.001) | 2.21E-03*** (0.000) |
| Silage analyses | 7.45E-04 (0.290) | 7.65E-04*** (0.000) | 1.20E-04 (0.067) |
| Metabolizable energy intake | 2.74E-02*** (0.000) | 3.29E-02*** (0.000) | 3.98E-02*** (0.000) |
| Total breeding value | 1.76E-04 (0.795) | 1.38E-03** (0.004) | 3.82E-04 (0.561) |
| Expected value of the heifer | 1.25E-04 (0.837) | 1.40E-05 (0.967) | 3.01E-04 (0.484) |
| Milk fever | -6.45E-04 (0.361) | 5.64E-04* (0.030) | 7.44E-04** (0.002) |
| Ketosis | 6.00E-04 (0.655) | -1.33E-04 (0.822) | 2.11E-04 (0.675) |
| Digestive/dietary disorders | -1.56E-04 (0.871) | -6.28E-05 (0.849) | 4.22E-05 (0.749) |
| Other diseases | 2.98E-04 (0.184) | -1.54E-05 (0.851) | 3.44E-05 (0.277) |
| R-squared | 0.9333 | 0.9269 | 0.9299 |
| Number of observation | 4863 | 12810 | 5756 |

Notes: Dependent variable: milk revenue. Shown are coefficient estimates (P -values) from a two-way fixed-effects (controlling for individual and time effects) panel data regression with robust standard errors in the presence of heteroskedasticity.

Farms with less than 20 cows are considered small, those with 20 to 50 cows are classified as medium, and those with more than 50 cows are categorized as large.

disparity is that the cross-sectional analysis finds some persisting confounding factors related to animal welfare and milk output, while the panel data analysis adequately adjusts for these factors. The partial significance observed for medium farms may also reflect heterogeneity in management and production structures, which allows welfare-related effects to be more easily detected in this group. The theoretical and empirical literature suggests the existence of regional differences (Wooldridge 2013) in institutions (Bijtebier et al. 2017), management practices (Hansson and Öhlmer 2008), and environmental factors (Gauily and Ammer 2020).

In our particular case, the current policy framework may affect the milk output and cause some differences between the farms and regions, but the effect in sample average may be rather small. Finland is divided into three principal support zones, A, B and C, with differing amounts of support administered to different regions. However, the majority of

the dairy farms in Finland are situated in the support zone C (which is further divided into subzones), mainly in the North Savo and Ostrobothnia regions, where they all operate under the same policy framework. These zones have substantial differences in natural conditions where farming is practiced, which may be a more important factor than the policy. Market and macroeconomic factors can also influence revenues and thus confound the animal welfare—economic performance relationship. Regionally varying farmgate prices, quality premiums for low somatic cell counts, contractual arrangements with processors, or cooperative membership may create correlations between animal welfare indicators and income that are not causal. For example, [Nightingale et al. \(2008\)](#) document that quality premium schemes for very low bulk-tank somatic cell count incentivize producers and can affect milk quality and income gains. Additionally, studies on vertical coordination in dairy supply chains highlight how contract terms and processor—farmer relationships can shape farmer revenues independently of on-farm practices ([Dries et al. 2009](#)). Data constraints prevent us from explicitly modelling these market variables; we therefore report this as an additional limitation.

Climatic and environmental conditions have an important effect on milk production, animal welfare and their relationship. Such an influence may take place in several complex forms such as temperature-related illness and fatalities. These effects could be attributed to changes in the immunological and endocrine systems ([Das et al. 2016](#)). Environmental factors also tend to show seasonality, for example, the increase in the number of somatic cells in milk during the warmer summer months when compared to the winter season ([Testa et al. 2017](#)). This influence manifests itself primarily in the form of heat stress, which elevates the body temperature of animals, leading to reduced feed consumption and, consequently, lower milk production ([Zimelman et al. 2010](#)). Ideally, we would have incorporate climatic and environmental factors more closely into the cross-sectional model to improve our understanding of their role, but data availability unfortunately prevented this approach. Year dummy variables were therefore included as controls to capture annual shocks and interannual environmental variation; however, they do not account for within-year seasonal differences (e.g. summer—winter effects). This specification accounted for differences in weather across years, but it does not address variations in geographical distribution or true seasonality. Although the results are not presented here, they show that including year effects does not alter the significance or direction of the relationship between the animal welfare index and milk production. The animal welfare index, constructed from four animal-based indicators (locomotory disorders, uterine disease, calf mortality, and somatic cell count (SCC)) is partly sensitive to climatic and environmental variations, particularly through heat stress and disease incidence, which may explain some of the observed temporal patterns.

Variations in aspects such as hygiene, housing conditions, and access to outdoor area across different farms likely has substantial impacts on the observed effect of the association between the animal welfare index and milk production. To empirically test this, specific housing characteristics were incorporated into the cross-sectional model. These variables included the barn type (indicating whether animals are tied or have freedom of movement) and the availability of outdoor access (presence or absence of access to open areas²). See Table A6 for results.

While a persistently negative and statistically significant effect was observed, it is essential to assess also the economic significance of the results using confidence intervals. For instance, when examining the baseline model (Model 1 in [Table 6](#)), the 95 per cent confidence interval for the animal welfare index ranged from a 0.004 to 0.008 per cent decrease in milk revenue per one-standard-deviation increase in the index, indicating a consistent and economically relevant negative association. When introducing additional confounding variables related to housing characteristics (Model 2 in [Table 6](#)), the estimated effect of the welfare index remained negative and significant, but the magnitude of the effect decreased, with a narrower 95 per cent confidence interval ranging from a 0.002 to 0.007 per cent

Table 6. The role of housing characteristics in the cross-sectional analysis.

| | Baseline model | | | Model with additional confounders | | |
|----------------------------------|----------------|--------------------|-------------|-----------------------------------|--------------------|-------------|
| | Coeff | 95% Conf. Interval | | Coeff | 95% Conf. Interval | |
| | | Lower bound | Upper bound | | Lower bound | Upper bound |
| Welfare index | -0.006 | -0.008 | -0.004 | -0.004 | -0.007 | -0.002 |
| Feed saving index | 0.001 | 0.000 | 0.002 | 0.001 | 0.000 | 0.002 |
| Dry matter intake | 0.036 | 0.035 | 0.038 | 0.037 | 0.036 | 0.038 |
| N utilization | 0.012 | 0.011 | 0.013 | 0.012 | 0.011 | 0.013 |
| P utilization | 0.001 | 0.001 | 0.002 | 0.001 | 0.001 | 0.002 |
| Milk urea | 0.013 | 0.012 | 0.013 | 0.013 | 0.012 | 0.013 |
| Silage analyses | -0.001 | -0.002 | -0.001 | -0.001 | -0.001 | -0.001 |
| Metabolizable energy intake | 0.104 | 0.092 | 0.115 | 0.101 | 0.090 | 0.111 |
| Total breeding value | 0.001 | 0.000 | 0.002 | 0.001 | 0.001 | 0.002 |
| Expected value of the heifer | 0.003 | 0.002 | 0.003 | 0.002 | 0.002 | 0.003 |
| Milk fever | 0.001 | 0.001 | 0.002 | 0.002 | 0.001 | 0.002 |
| Ketosis | -0.001 | -0.002 | 0.001 | 0.000 | -0.002 | 0.001 |
| Digestive/dietary disorders | -0.001 | -0.002 | 0.000 | -0.001 | -0.002 | -0.001 |
| Other diseases | 0.000 | -0.001 | 0.000 | 0.000 | 0.000 | 0.000 |
| Summer Pasture/Winter Indoor | | | | 0.033 | 0.027 | 0.038 |
| Summer Pasture/Winter Recreation | | | | 0.030 | 0.021 | 0.038 |
| Summer Garden/Winter Indoor | | | | 0.031 | 0.021 | 0.041 |
| Summer Garden/Winter Outdoor | | | | 0.030 | 0.015 | 0.046 |
| Barn type (free-stall barn) | | | | -0.004 | -0.009 | 0.001 |
| R-squared | | 0.2613 | | | 0.2664 | |
| Number of observation | | 24989 | | | 24989 | |
| Wald χ^2 test of equality | | | | | | 50.98 |
| P-value | | | | | | $P < 0.001$ |

Statistically significant confidence intervals at the 5 per cent level are in bold.

decrease per one-standard-deviation increase. This reduction in magnitude suggests that part of the association observed in the baseline model was explained by differences in housing and management conditions rather than welfare alone, thereby reducing the economic importance of the welfare effect once these confounders are controlled for. A Wald χ^2 test of equality ($\chi^2 = 50.98$, $p < 0.001$) confirms that the coefficients for the welfare index differ significantly between the two models, indicating that the inclusion of housing variables explains part of the variation previously attributed to animal welfare.

5. Conclusion and implications

An important topic of discussion within the field of agricultural economics is how to balance ethical considerations for animal welfare with the economic constraints faced by farmers when implementing welfare-improving measures (Lusk and Norwood 2011). There are at least two reasons why societies might want to establish an explicit link between animal welfare improvements and their economic implications. The first relates to the ethical dimension of animal welfare, which is closely connected to sustainability transitions (Weikard 1992; Ahmadi et al. 2020; Sandoe et al. n.d.). In other words, it is about ensuring what is morally right for animals while advancing a more sustainable food system. The second reason is that understanding the economic implications of animal welfare measures helps farmers and policymakers evaluate how welfare investments influence farm profitability and long-term sustainability (Christensen et al. 2012).

The current analysis examined the effect of animal welfare on milk revenue by using a large sample of Finnish dairy farms over the period of 2010–2017 and employing multiple econometric models. In cross-sectional estimations, a persistent and negative association between the animal welfare index and milk revenue was found, and this cannot be accounted for by typical production and health covariates. However, when using panel data regressions with farm and year fixed effects, no overall causal relationship between the welfare index and milk production was identified, except for medium-sized farms where the association remained significant. Naturally, this raises the question of where the strong cross-sectional relationship originates. We discussed the factors that may have contributed to these results. While the data did not allow us to observe all of the differences in specific on-farm management practices, variables capturing housing conditions, such as barn type and outdoor access, were included in the extended specification. Although the significant association between the welfare index and milk production remains, its economic importance decreases once these housing-related confounders are controlled for.

Our results have important research and policy implications. In terms of research, Most previous studies report a positive association between animal welfare and farm economic performance, suggesting that better welfare improves productivity and profitability. However, our analysis shows no evidence of a causal effect once farm-specific heterogeneity is controlled for (af Sandeberg et al. 2023). This finding implies that the observed welfare—income relationship in high-income countries such as Finland may largely reflect structural and management differences rather than a direct causal mechanism (Lansink et al. 2002). This calls for further research to disentangle the underlying channels linking welfare and economic outcomes, so that future policies can target the most effective levers for improving both farm sustainability and animal well-being. From a policy perspective, our findings should be viewed as offering structural insights into the welfare—performance relationship rather than as direct policy guidance, given that the analysis covers the 2010–2017 period. The observed association without clear causality indicates that improving welfare alone may not automatically raise income. Policy design should therefore emphasise integrated approaches that connect animal-health management and efficiency incentives. Incentive schemes based on composite performance indicators, such as milk yield per lactation day, longevity, or treatment incidence, can better align welfare improvements with productivity and avoid simplistic assumptions that higher welfare always increases revenue.

It is important to recognise that the results reflect the conditions of the study period only. The estimated relationships describe how animal welfare and milk revenue interacted within Finnish dairy farming between 2010 and 2017. Since then, the sector has evolved in ways that could influence this association. The introduction of the CAP 2023–2027 brought new instruments, such as eco-schemes and stricter conditionality, that directly reward welfare-enhancing practices. These policy incentives may strengthen the economic rationale for improving welfare compared with the earlier period. At the same time, structural adjustments have continued: the number of farms has declined, herds have grown larger, and automation and health-monitoring technologies have become more widespread. As noted in the results, environmental and climatic variability may also influence both welfare and productivity; the dataset lacks regional identifiers and climatic variables, and consequently region-specific, time-varying weather shocks cannot be modelled in our specifications. Together, these factors suggest that the estimated relationships should be interpreted within the structural and environmental context of the study period rather than as current policy evidence.

Management practices are central to these shifts. For instance, the growing adoption of free-stall barns with automated milking and health sensors enables earlier detection of disease and better mobility, likely improving both welfare scores and productivity. Similarly, precision feeding and herd-monitoring systems reduce variation in nutrition and stress, improving both animal comfort and milk yield. These technological and managerial improvements can weaken or even reverse the earlier association observed in our data, where lower welfare scores coincided with lower revenue mainly due to poorer management quality. At the same time, behavioural factors must also be considered in future research (Dessart et al. 2019), as farmers' moral concerns (Kielland et al. 2010) and personality traits (Austin et al. 2005) can significantly shape management choices and the adoption of welfare-enhancing practices.

Consequently, while the 2010–2017 data provide valuable evidence on the structural linkages between animal welfare and farm performance during that period, the results should not be interpreted as current policy evidence. They highlight instead that management quality is the key mechanism connecting animal welfare and economic outcomes. Future research using more recent data should examine how evolving technologies, farm structures, and policy incentives interact with management to reshape this relationship. Such analyses would help determine whether improved welfare now translates more directly into higher productivity and profitability under the new policy and technological environment.

Acknowledgments

This research is part of the HoloRuminant project.

Conflict of interest

The authors declare that they have no conflict of interest.

Funding

The authors received financial support from the European Union Horizon 2020 Programme for Research, Technological Development, and Demonstration under grant agreement no. 101000213.

Data availability statement.

The data supporting this study were obtained from the databases of ProAgria, a rural advisory organization in Finland, and Faba, the Finnish Animal Breeding Association. Access

to these data is restricted, as they were used under license within the EU project HoloRuminant. For further information regarding data access, please contact the corresponding author.

End notes

- 1 We have also performed a principal component analysis (PCA) of the four standardized indicators. The first two components explained only about 57 per cent of the total variance, with no single component capturing a dominant share. In particular, the second component loaded positively and fairly consistently across all four indicators, resembling our composite index. However, given that the variance explained by PCA was limited and that the weights derived from PCA do not have a straightforward interpretation, we rely on the equal-weighted composite index as our main measure, as it is more transparent and offers greater ease of interpretation.
- 2 A set of dummy variables for each of the outdoor access conditions was introduced. A single dummy variable, which took the value 1 if the cows can move freely and 0 otherwise, was included for the barn type.

References

- af Sandeberg A. et al. (2023) 'Review: Linking Animal Health Measures in Dairy Cows to Farm-level Economic Outcomes: a Systematic Literature Mapping.' *Animal*, 17:100971. <https://doi.org/10.1016/j.animal.2023.100971>
- Ahmadi B. V., Moran D. and D'Eath R. (2020) *The Economics of Farm Animal Welfare: Theory, Evidence and Policy*. United Kingdom: CABI. <https://doi.org/10.1079/9781786392312.0000>
- Ahmed H. et al. (2020) 'Assessing Economic Consequences of Improved Animal Welfare in Swedish Cattle Fattening Operations Using a Stochastic Partial Budgeting Approach.' *Livestock Science*, 232:103920. <https://doi.org/10.1016/j.livsci.2020.103920>
- Ahmed H. et al. (2023) 'Animal Welfare Efforts and Farm Economic Outcomes: Evidence from Swedish Beef Production.' *Agricultural and Resource Economics Review*, 52:498–519. <https://doi.org/10.1017/age.2023.8>
- Alvarez R. (2022) 'Comparing Productivity of Organic and Conventional Farming Systems: a Quantitative Review.' *Archives of Agronomy and Soil Science*, 68:1947–58. <https://doi.org/10.1080/03650340.2021.1946040>
- Austin E. J. et al. (2005) 'Attitudes to Farm Animal Welfare.' *Journal of Individual Differences*, 26:107–20. <https://doi.org/10.1027/1614-0001.26.3.107>
- Barnes A. P. et al. (2011) 'The Effect of Lameness Prevalence on Technical Efficiency at the Dairy Farm Level: an Adjusted Data Envelopment Analysis Approach.' *Journal of Dairy Science*, 94:5449–57. <https://doi.org/10.3168/jds.2011-4262>
- Bell M. J. and Wilson P. (2018) 'Estimated Differences in Economic and Environmental Performance of Forage-based Dairy Herds across the UK.' *Food and Energy Security*, 7:1–12. <https://doi.org/10.1002/fes3.127>
- Bijttebier J. et al. (2017) 'Low-input Dairy Farming in Europe: Exploring a Context-specific Notion.' *Agricultural Systems*, 156:43–51. <https://doi.org/10.1016/j.agsy.2017.05.016>
- Broom D. M. (1991) 'Animal Welfare: Concepts and measurement2.' *Journal of Animal Science*, 69:4167–75. <https://doi.org/10.2527/1991.69104167x>
- Bruijnijns M. R. N., Hogeveen H. and Stassen E. N. (2013) 'Measures to Improve Dairy Cow Foot Health: Consequences for Farmer Income and Dairy Cow Welfare.' *Animal*, 7:167–75. <https://doi.org/10.1017/S1751731112001383>
- Christensen T. et al. (2012) 'How Can Economists Help to Improve Animal Welfare?' *Animal Welfare*, 21:1–10. <https://doi.org/10.7120/096272812x13345905673449>
- Costa A. et al. (2020) 'Milk Somatic Cell Count and Its Relationship with Milk Yield and Quality Traits in Italian Water Buffaloes.' *Journal of Dairy Science*, 103:5485–94. <https://doi.org/10.3168/jds.2019-18009>
- Das R. et al. (2016) 'Impact of Heat Stress on Health and Performance of Dairy Animals: a Review.' *Veterinary World*, 9:260–8. <https://doi.org/10.14202/vetworld.2016.260-268>
- Dawkins M. S. (2017) 'Animal Welfare and Efficient Farming: Is Conflict Inevitable?' *Animal Production Science*, 57:201. <https://doi.org/10.1071/AN15383>

- Dekkers J. C. M., Van Erp T. and Schukken Y. H. (1996) 'Economic Benefits of Reducing Somatic Cell Count under the Milk Quality Program of Ontario.' *Journal of Dairy Science*, 79:396–401. [https://doi.org/10.3168/jds.S0022-0302\(96\)76378-6](https://doi.org/10.3168/jds.S0022-0302(96)76378-6)
- Dessart F. J., Barreiro-Hurlé J. and van Bavel R. (2019) 'Behavioural Factors Affecting the Adoption of Sustainable Farming Practices: a Policy-oriented Review.' *European Review of Agricultural Economics*, 46:417–71. <https://doi.org/10.1093/erae/jbz019>
- Dillon E. J., Hennessy T. and Cullinan J. (2015) 'Measuring the Economic Impact of Improved Control of Sub-clinical Mastitis in Irish Dairy Herds.' *The Journal of Agricultural Science*, 153:666–75. <https://doi.org/10.1017/S0021859614001178>
- Dries L. et al. (2009) 'Farmers, Vertical Coordination, and the Restructuring of Dairy Supply Chains in Central and Eastern Europe.' *World Development*, 37:1742–58. <https://doi.org/10.1016/j.worlddev.2008.08.029>
- Duncan I. J. H. (1993) 'Welfare Is to Do with What Animals Feel.' *Journal of Agricultural and Environmental Ethics*, 6:8–14.
- EU (2021) *The Common Agricultural Policy (CAP) and the Treaty*. European Parliament. <https://www.europarl.europa.eu/factsheets/en/sheet/103/the-common-agricultural-policy-cap-and-the-treaty>
- Fraser D. (2003) 'Assessing Animal Welfare at the Farm and Group Level: the Interplay of Science and Values.' *Animal Welfare*, 12:433–43. <https://doi.org/10.1017/S0962728600026038>
- Galvão K. N., Bicalho R. C. and Jeon S. J. (2019) 'Symposium Review: the Uterine Microbiome Associated with the Development of Uterine Disease in Dairy Cows.' *Journal of Dairy Science*, 102:11786–97. <https://doi.org/10.3168/jds.2019-17106>
- Gauly M. and Ammer S. (2020) 'Review: Challenges for Dairy Cow Production Systems Arising from Climate Changes.' *Animal*, 14:s196–s203. <https://doi.org/10.1017/S1751731119003239>
- Gonyou H. W. (1986) 'Symposium on "Indices to Measure Animal Well-Being".' *Journal of Animal Science*, 62:1769–75. <https://doi.org/10.2527/jas1986.6261769x>
- Hansson H., Manevska-Tasevska G. and Asmild M. (2018) 'Rationalising Inefficiency in Agricultural Production—the Case of Swedish Dairy Agriculture.' *European Review of Agricultural Economics*, 47:1–24. <https://doi.org/10.1093/erae/jby042>
- Hansson H. and Öhlmér B. (2008) 'The Effect of Operational Managerial Practices on Economic, Technical and Allocative Efficiency at Swedish Dairy Farms.' *Livestock Science*, 118:34–43. <https://doi.org/10.1016/j.livsci.2008.01.013>
- Hansson H., Szczensa-Rundberg M. and Nielsen C. (2011) 'Which Preventive Measures against Mastitis Can Increase the Technical Efficiency of Dairy Farms?' *Animal*, 5:632–40. <https://doi.org/10.1017/S1751731110002247>
- Henningsen A. et al. (2018) 'The Relationship between Animal Welfare and Economic Performance at Farm Level: a Quantitative Study of Danish Pig Producers.' *Journal of Agricultural Economics*, 69:142–62. <https://doi.org/10.1111/1477-9552.12228>
- Hogeveen H., Steeneveld W. and Wolf C. A. (2019) 'Production Diseases Reduce the Efficiency of Dairy Production: a Review of the Results, Methods, and Approaches regarding the Economics of Mastitis.' *Annual Review of Resource Economics*, 11:289–312. <https://doi.org/10.1146/annurev-resource-100518-093954>
- Huijps K., Lam T. J. and Hogeveen H. (2008) 'Costs of Mastitis: Facts and Perception.' *Journal of Dairy Research*, 75:113–20. <https://doi.org/10.1017/S0022029907002932>
- Kielland C. et al. (2010) 'Dairy Farmer Attitudes and Empathy toward Animals Are Associated with Animal Welfare Indicators.' *Journal of Dairy Science*, 93:2998–3006. <https://doi.org/10.3168/jds.2009-2899>
- Lansink A. O., Pietola K. and Bäckman S. (2002) 'Efficiency and Productivity of Conventional and Organic Farms in Finland 1994–1997.' In *European Review of Agricultural Economics* (Vol. 29, Issue pp. 51–65). <https://doi.org/10.1093/erae/29.1.51>
- Lawson L. G. et al. (2004) 'Relationships of Efficiency to Reproductive Disorders in Danish Milk Production: a Stochastic Frontier Analysis.' *Journal of Dairy Science*, 87:212–24. [https://doi.org/10.3168/jds.S0022-0302\(04\)73160-4](https://doi.org/10.3168/jds.S0022-0302(04)73160-4)
- Luke (2024) 'Number of Livestock in Spring of 2023.' <https://www.luke.fi/en/statistics/number-of-livestock/number-of-livestock-in-spring-of-2023>
- Lusk J. L. and Norwood F. B. (2011) 'Animal Welfare Economics.' *Applied Economic Perspectives and Policy*, 33 463–83. <https://doi.org/10.1093/aep/prr036>

- McGlone J. J. (2001) 'Farm Animal Welfare in the Context of Other Society Issues: toward Sustainable Systems.' *Livestock Production Science*, 72:75–81. [https://doi.org/10.1016/S0301-6226\(01\)00268-8](https://doi.org/10.1016/S0301-6226(01)00268-8)
- McInerney J. (2004) *Animal Welfare, Economics and Policy; Report on a Study Undertaken for the Farm & Animal Health Economics Division*. London, UK: DEFRA.
- Nielsen S. S. et al. (2023) 'Welfare of Dairy Cows.' *EFSA Journal*, 21:e07993. <https://doi.org/10.2903/j.efs.2023.7993>
- Nightingale C. et al. (2008). 'Influence of Variable Milk Quality Premiums on Observed Milk Quality.' *Journal of Dairy Science*, 91:1236–44. <https://doi.org/10.3168/jds.2007-0609>
- Ortiz-Pelaez A. et al. (2008) 'Calf Mortality as a Welfare Indicator on British Cattle Farms.' *The Veterinary Journal*, 176:177–81. <https://doi.org/10.1016/j.tvjl.2007.02.006>
- Oster E. (2019) 'Unobservable Selection and Coefficient Stability: Theory and Evidence.' *Journal of Business & Economic Statistics*, 37:187–204. <https://doi.org/10.1080/07350015.2016.1227711>
- Parlasca M. et al. (2023) 'How and Why Animal Welfare Concerns Evolve in Developing Countries.' *Animal Frontiers*, 13:26–33. <https://doi.org/10.1093/af/vfac082>
- Pérez-Méndez J. A., Roibás D. and Wall A. (2020) 'Somatic Cell Counts, Reproduction Indicators, and Technical Efficiency in Milk Production: a Stochastic Frontier Analysis for Spanish Dairy Farms.' *Journal of Dairy Science*, 103:7141–54. <https://doi.org/10.3168/jds.2019-17146>
- Puerto M. A. et al. (2021) 'The Hidden Cost of Disease: II. Impact of the First Incidence of Lameness on Production and Economic Indicators of Primiparous Dairy Cows.' *Journal of Dairy Science*, 104:7944–55. <https://doi.org/10.3168/jds.2020-19585>
- Reader J. D. et al. (2011) 'Effect of Mobility Score on Milk Yield and Activity in Dairy Cattle.' *Journal of Dairy Science*, 94:5045–52. <https://doi.org/10.3168/jds.2011-4415>
- Roche S. et al. (2023) 'Calf Management and Welfare in the Canadian and US Dairy Industries: Where Do We Go from Here?' *Journal of Dairy Science*, 106:4266–74. <https://doi.org/10.3168/jds.2022-22793>
- Rommel J. and Weltin M. (2021) 'Is There a Cult of Statistical Significance in Agricultural Economics?' *Applied Economic Perspectives and Policy*, 43:1176–91. <https://doi.org/10.1002/aep.13050>
- Sandgren C., Lindberg A. and Keeling L. (2009) 'Using a National Dairy Database to Identify Herds with Poor Welfare.' *Animal Welfare*, 18:523–32. <https://doi.org/10.1017/S0962728600000944>
- Sandoe P., Grisp R. and Holtug N. (n.d.). *Ethics*. In: Appleby, M.C., Hughes, B.O. (Eds.), *Animal Welfare*, (pp. 3–17). CAB International.
- Santman-Berends I. M. G. A., Schukken Y. H. and van Schaik G. (2019) 'Quantifying Calf Mortality on Dairy Farms: Challenges and Solutions.' *Journal of Dairy Science*, 102:6404–17. <https://doi.org/10.3168/jds.2019-16381>
- Schulte H. D. et al. (2018) 'Let the Cows Graze: an Empirical Investigation on the Trade-off between Efficiency and Farm Animal Welfare in Milk Production.' *Land Use Policy*, 79:375–85. <https://doi.org/10.1016/j.landusepol.2018.07.005>
- Seppä-Lassila L. et al. (2016) 'Management Factors Associated with Mortality of Dairy Calves in Finland: a Cross Sectional Study.' *The Veterinary Journal*, 216:164–7. <https://doi.org/10.1016/j.tvjl.2016.07.008>
- Skevas T. and Cabrera V. E. (2020) 'Measuring Farmers' dynamic Technical and Udder Health Management Inefficiencies: the Case of Wisconsin Dairy Farms.' *Journal of Dairy Science*, 103:12117–27. <https://doi.org/10.3168/jds.2020-18656>
- Stott A. et al. (2012) 'Interactions between Profit and Welfare on Extensive Sheep Farms.' *Animal Welfare*, 21:57–64. <https://doi.org/10.7120/096272812x13345905673683>
- Testa F. et al. (2017) 'Study of the Association of Atmospheric Temperature and Relative Humidity with Bulk Tank Milk Somatic Cell Count in Dairy Herds Using Generalized Additive Mixed Models.' *Research in Veterinary Science*, 114:511–7. <https://doi.org/10.1016/j.rvsc.2017.09.027>
- Tonsor G. T. and Wolf C. A. (2019) 'US Farm Animal Welfare: an Economic Perspective.' *Animals*, 9:367. <https://doi.org/10.3390/ani9060367>
- Uetake K. (2013) 'Newborn Calf Welfare: a Review Focusing on Mortality Rates.' *Animal Science Journal*, 84:101–5. <https://doi.org/10.1111/asj.12019>
- van der Voort M. et al. (2014) 'A Stochastic Frontier Approach to Study the Relationship between Gastrointestinal Nematode Infections and Technical Efficiency of Dairy Farms.' *Journal of Dairy Science*, 97:3498–508. <https://doi.org/10.3168/jds.2013-7444>
- Villetaz Robichaud M. et al. (2018) 'Is the Profitability of Canadian Tiestall Farms Associated with Their Performance on an Animal Welfare Assessment?' *Journal of Dairy Science*, 101:2359–69. <https://doi.org/10.3168/jds.2017-13316>

- Weikard H. P. (1992) *Der Beitrag der Ökonomik zur Begründung von Normen des Tier- und Artenschutzes: Eine Untersuchung zu Praktischen und Methodologischen Problemen der Wirtschaftsethik*. Berlin: Duncker & Humblot.
- Wooldridge J. M. (2013) 'Introductory Econometrics: a Modern Approach. 5th.' In *South-Western Cengage Learning*. Mason, OH, USA: South-Western Cengage Learning.
- Ziliak S. T. and McCloskey D. N. (2004) 'Size Matters: the Standard Error of Regressions in the American Economic Review.' *The Journal of Socio-Economics*, 33 527–46. <https://doi.org/10.1016/j.socec.2004.09.024>
- Zimbelman R. B., Baumgard L. H. and Collier R. J. (2010) 'Effects of Encapsulated Niacin on Evaporative Heat Loss and Body Temperature in Moderately Heat-stressed Lactating Holstein Cows.' *Journal of Dairy Science*, 93:2387–94. <https://doi.org/10.3168/jds.2009-2557>