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Animal health and welfare state and technical efficiency of dairy farms: possible synergies

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Abstract

This study sought to investigate whether animal health and welfare state and changes were associated with technical efficiency in a sample of 34 Austrian dairy farms. Health and welfare were assessed twice using the Welfare Quality® (WQ) assessment protocol for dairy cattle. Following a baseline welfare assessment, farm-specific health and welfare planning was conducted on the farms. This included the identification, selection and implementation of measures in housing and management that aimed at improving health and welfare states. One year after implementation, farms were reassessed to evaluate changes in health and welfare states and consequences for farms' technical efficiency were analysed using the Malmquist index. Our results indicated that farms with a higher health state (WQ principle score 'Good health') achieved higher technical efficiencies. However, we could not show that changes in the welfare state within a one-year period affected technical efficiency: across all farms, technical efficiency remained stable and Malmquist indices (indicating efficiency and technological change) could not be explained by the different welfare scores. Nevertheless, our study showed data envelopment analysis to be a valuable method for analysing the relationship between animal welfare and farm success and our results indicate substantial potential synergies between these two aspects.

Keywords: *animal welfare, dairy cows, data envelopment analysis, Malmquist index, on-farm assessment, Welfare Quality®*

Introduction

Animal health and welfare plays an important role in successful dairy cattle husbandry. However, the prevalences found in on-farm surveys of, for example, health-related welfare impairments often exceed the levels beyond which experts consider improvement necessary (Whay *et al* 2003; Green *et al* 2007; Leach *et al* 2010; Tremetsberger & Winckler 2015). The extent to which health and welfare may be improved has been investigated, for example, in the case of mastitis (eg Green *et al* 2007; Ivemeyer *et al* 2008; Tremetsberger *et al* 2015) and lameness (eg Main *et al* 2012). These studies report primarily on the effect of intervention measures addressing management and provision of resources at the farm level on animal health (ie udder and leg health, respectively) and welfare of dairy cows. However, animal welfare is not only shaped by animal health. A comprehensive view on animal welfare also includes the animals' feelings (affective state) and their ability to express natural behaviour (natural living) (Fraser *et al* 1997).

In the past decade, attempts have been made to assess, scientifically, animal welfare at the farm level and comprehensive protocols, such as the Welfare Quality® (WQ) assessment protocol for cattle, have been developed (Welfare Quality® 2009). Recent studies on dairy cow and beef cattle welfare have been based on this protocol (Ivemeyer *et al* 2012; Andreasen *et al* 2013; De Vries *et al* 2013; Kirchner *et al* 2014; Tremetsberger *et al* 2015). The assessment allows welfare problems to be identified, thereby seeking to facilitate introduction of appropriate interventions on the farms, eg in terms of changes in management routines and housing systems.

Compromised health and welfare states may also have economic implications (eg Kossaibati & Esslemont 1997; Huijps *et al* 2008). For instance, Hansson *et al* (2011) identified preventive measures against mastitis, such as revision of hygiene routines, as beneficial for the whole-farm economic outcome. Farms' economic performance can also be expressed in terms of technical efficiency, basically benchmarking input-to-output relations of single farms (Coelli *et al* 2005). Technical efficiency has been used in several studies to assess the economic performance of dairy farms in different production systems (Barnes *et al* 2011; Hansson *et al* 2011; Kelly *et al* 2012a; Steeneveld *et al* 2012; Heinrichs *et al* 2013). With regard to animal welfare, Barnes *et al* (2011) showed in a study involving 80 UK farms that farms with high lameness prevalence were significantly less technically efficient than farms with satisfactory leg health. More recently, Allendorf and Wettemann (2015) showed for dairy farms in Germany that indicators such as cow losses, replacement rate and calving interval correlate negatively with technical efficiency.

However, to our best knowledge, there has yet to be any studies into the consequences of shifts in the health and welfare states of cattle on the technical efficiency of the farm. Thus, the aim of the present study was to analyse the impact of animal health and welfare outcomes, according to the WQ protocol (Welfare Quality® 2009), on the technical efficiency of 34 Austrian dairy farms. Technical efficiency was derived from a data envelopment model (DEA), which allows for consideration of multiple inputs and outputs while not requiring identical units (Charnes *et al* 1978), enabling us to consider non-monetised production factors. Furthermore, we analysed the impact of changes in health and welfare states on technical efficiency. In order to analyse such changes, we applied a Malmquist index (ie total factor productivity change) model, again based on a DEA model. We hypothesised, firstly, a positive correlation between health and welfare states and technical efficiency, and secondly that an increase in health and welfare would be accompanied by a positive technical efficiency change.

Materials and methods

Farm set description

Data were collected from 34 Austrian family-run dairy farms (mean herd size: 35 cows, range: 24–56 cows), that had agreed to participate in an animal health and welfare planning project (Tremetsberger *et al* 2015). On all the farms, dairy cows were kept in cubicle housing systems without access to pasture; eleven herds had permanent access to an outdoor run. The predominant breed was Austrian Fleckvieh with 25 herds consisting of more than 90% Fleckvieh. The remaining nine farms kept either Brown Swiss (three farms), Holstein Friesian (two farms), or a mixture of all three breeds (four herds). Dairy cows were either fed grass silage and hay or rations consisting of maize silage, grass silage and hay. Concentrates were fed manually on the feed bunk, by total mixed rations, or via concentrate dispensers, respectively.

Welfare assessment

During the study period, all farms were visited three times by the same observer. A one-day visit at the beginning of the study (winter 2011/12; Year 0) was used for data collection based on the Welfare Quality® assessment protocol for dairy cattle (Welfare Quality® 2009). The assessment rests, primarily, on animal-based indicators and all results are expressed on the herd level. During the on-farm assessment, dairy cows were individually scored for clinical health and cleanliness. Behaviour was assessed using an avoidance distance test, observation of spontaneous social and resting behaviour as well as qualitative behaviour assessment of the herd. Provision of resources (eg stocking density, cubicle design, composition of feed) and management procedures (eg milking hygiene, claw trimming, calving management) were assessed using checklists and questionnaire-based interviews with the farmer on the day of assessment (for details, see Welfare Quality® 2009; Tremetsberger *et al* 2015). During a subsequent visit, taking place a mean (± SD) of 55 (± 26) days after the initial visit, animal health and welfare planning was carried out on the farms (see below). Finally, dairy cows' health and welfare states were reassessed, in accordance with the procedures used during the first visit, on average 368 (± 11) days after the health and welfare planning visit (Year 1). During this third farm visit, data for economic calculations were collected though a questionnaire-based interview with the farmer. This included questions on three input factors (average herd size, annual labour, concentrate use; see below) and one output factor (milk yield per cow and year) in the period between the first and third farm visit, respectively (Year 1). Concerning annual labour, annual work hour estimates were specified for each working step, namely milking, feeding, hygiene measures and herd management. Furthermore, it was assessed whether inputs and output had changed during the study period compared to the 12-month period prior to the first farm visit in order to calculate values for Year 0.

Health and welfare planning

Formulating farm-individual health and welfare plans followed key aspects as highlighted by Vaarst *et al* (2011): i) assessment of health and welfare states; ii) analysis of outcomes; iii) feedback of outcomes to the farmer; iv) (farm-specific and targeted) advice related to health and welfare issues; and v) constant review and adaptation of the formulated plan. In the present study, the health and welfare plans were based on the farm-individual outcomes of the welfare assessment at the measure level (eg herd prevalence of lame animals) and on the situation with regard to resources and management. Farmers were asked to address one or several health and welfare focus areas and the decision-making process was only facilitated by the researcher. After completion of all plans, the focus areas were categorised into 'udder health', 'metabolic health', 'leg health', 'cleanliness', 'lying comfort' and 'social behaviour and human-animal relationship.' The aim was to develop changes in management practices and housing system to improve health and welfare, which were specific for each farm. The individually selected measures were written down in the health and welfare plan by the farmer him- or herself and farmers were encouraged to implement these measures. For example, addressing the focus area 'udder health' comprised improvement measures focusing on cow hygiene (eg stall maintenance), milking hygiene (eg teat cup disinfection) or mastitis management (eg bacterial examination of milk samples). A more detailed description of the planning process and an overview of improvement measures included in the health and welfare plans is provided in Tremetsberger *et al* (2015).

None of the farms used contracted advisory services with regard to herd management. Standard sources of advice were farm veterinarians and sporadically (company bound) nutrition advisors. Additionally, a limited number of farms participated in farmer groups focusing on dairy production.

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Table 1 Mean (± SD), type, description, data source and minimum and maximum values for output and input factors used in data envelopment analysis and Malmquist indices calculation for Austrian dairy farms (n = 34) in Year 0 and Year 1.

Factor	Type	Description	Data source	Unit	Year 0		Year 1	
					Mean (± SD)	Range	Mean (± SD)	Range
Milk yield	Output	Annual milk yield per herd	National milk recording scheme	1,000 kg per herd per year	244 (± 62)	142–452	253 (75)	144–510
Herd size	Input	Dairy cows (n) at time of assessment	Farm assessment	Number of dairy cows	35 (± 7)	24–56	36 (8)	22–63
Annual labour	Input	Annual labour with respect to dairy cows	Farmer questionnaire	Hours per herd per year	2,338 (± 695)	1,162–4,208	2,361 (753)	1,300–4,381
Concentrate use	Input	Maximum amount of concentrates	Farmer questionnaire	Kg per herd per day	292 (± 104)	75–473	284 (108)	81–504

Technical efficiency and Malmquist index

The methodology underlying technical efficiency estimation is based on the fact that dairy farms combine inputs to produce outputs with varying degrees of efficiency. Technical efficiency is defined as "the ability to obtain maximal output from a given set of inputs" (Coelli *et al* 2005). On a whole farm scale, it can be analysed by applying data envelopment analysis (Charnes *et al* 1978). This method allows the formulation of a best-practice frontier over all observed data points, eg farms. The farms operating at their highest level of efficiency lie on the frontier and the others are radially measured against this frontier. Technical efficiency scores can range from 0 to 1 with values of 1 indicating fully efficient farms in the present sample. To calculate technical efficiency, one output was considered explained by three inputs in Year 0 and Year 1 (Table 1). Following other studies investigating technical efficiency of dairy systems (Barnes *et al* 2011; Kelly *et al* 2012a), milk yield was chosen as the output as this reflects the main product sold by a dairy farm. Herd size, annual labour and concentrate use were included directly or indirectly (as proxies) representing agricultural production factors (Barnes *et al* 2011). In order to obtain reliable results, it is preferable for the sample size to be greater than twice the product of inputs and outputs (Dyson *et al* 2001), which was ensured in the present study. Since our study farms basically belonged to the same size and intensity classes, we did not expect significant size effects and consequently applied a constant return to scale (CRS) model.

Data envelopment analysis is a suitable method for determining the efficiency of farms at a particular point in time, relative to other farms included in the sample. However, the method does not allow for a direct calculation of efficiency changes over time. In order to account for such temporal aspects, the Malmquist total factor productivity index may be applied. This index, first proposed by Malmquist (1953) and further developed by, amongst others, Färe *et al* (1994), considers productivity as the ratio of outputs to inputs and can be applied to calculate the total factor productivity change. For two periods, t and t+1, the Malmquist index for the i-th farm can be represented by the following distance function:

$$M_{it}(x_{it},y_{it},x_{i,t+1},y_{i,t+1}) = \frac{\Delta_{i,t+1}(x_{i,t+1},y_{i,t+1})}{\Delta_{it}(x_{it},y_{it})} \cdot \left[\frac{\Delta_{it}(x_{i,t+1},y_{i,t+1})}{\Delta_{i,t+1}(x_{i,t+1},y_{i,t+1})} \cdot \frac{\Delta_{it}(x_{it},y_{it})}{\Delta_{i,t+1}(x_{it},y_{it})}\right]^{2}$$

$$= EC_{it} \cdot TC_{it}$$

This index can be decomposed into efficiency change and technological change (first term [EC_{it}] and second term [TC_{it}], respectively, in the above equation) (Färe *et al* 1994). Firstly, efficiency change characterises the shift in the position of a farm relative to the production frontier ('catching up'). Efficiency change shows how much closer, or further away, the farm in question has moved to the frontier over time. Secondly, technological change illustrates the shift in the production frontier over time ('technical change' or 'innovation'). This component indicates whether the best-practice frontier has improved, stagnated or deteriorated. The decomposition of the Malmquist index makes it possible to separate the progress or regress in technical efficiency from year-to-year from shifts in the frontier itself (Färe *et al* 1994; Tone 2004).

Figure 1 illustrates these relationships for a given Farm A, in a case where only two inputs, x1 and x2, and one output, y are used. The best-practice frontiers F_t and F_{t+1} mark the most efficient combinations of inputs and output for each time-point, t and t+1, respectively (Figure 1). Farm A is inefficient in both years, as it is not located on the respective frontier. Efficiency change (EC) for farm A indicates if and how the farm has changed its position relative to the frontier and can be described with the following equation:

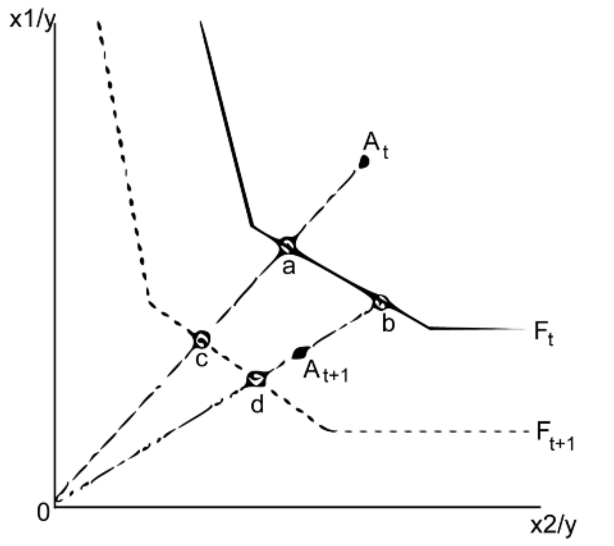
$$EC_{At} = \left(\frac{0d}{0A_{t+1}}\right) \div \left(\frac{0a}{0A_t}\right)$$

Farm A increased in technical efficiency from time t to time t+1, as it has moved proportionally closer to the respective frontier, therefore, the efficiency change component would be larger than 1. Technology change (TC) for farm A marks the shifts in the frontier and is depicted as in the following equation:

$$TC_{At} = \left(\frac{0b}{0d} \cdot \frac{0a}{0c}\right)^{\frac{1}{2}}$$

Advancement in technology has occurred for farm A, as the frontier has moved closer to the origin, thus less input is needed for the same level of output production. A drawback of DEA and consequently also of the Malmquist index is that the efficiency scores may be influenced by sampling variation and are likely to be biased towards the upper end.

Figure 1



Malmquist index for farm A under constant returns to scale production frontiers using two inputs (x1 and x2 related to output y) for two time-periods t and t+1; a and d represent the benchmark positions on the frontier if the farm would be fully efficient in time-periods t and t+1, respectively; b and c are the benchmark positions on the frontiers of the respective other time-periods.

Simar and Wilson (1998) recommended a "smoothed bootstrap approach" to account for this bias. This is especially important if the sample is small, as is the case in the present study. The application of such a bootstrapping approach provides bias-corrected efficiencies and constructs confidence intervals for the 'true' efficiency score.

Data analysis

WQ assessment results were calculated according to the formulae published in the WQ assessment protocol for dairy cattle. Mean values for animal-based WQ-measures assessed on-farm are presented in Supplementary Table S1 (see the supplementary material to papers published in *Animal Welfare* on the UFAW website: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). In brief, scores which may range from 0 (poor welfare state) to 100 (excellent welfare state) were first calculated for 12 criteria that are then aggregated into four principle scores ('Good feeding', 'Good housing', 'Good health', 'Appropriate behaviour'; see Table 2 (supplementary material to papers published in *Animal Welfare* on the UFAW website: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material) and for a detailed description see Welfare Quality® 2009). Overall WQ classification is based on the principles scores and revealed 18 and 15 'enhanced' and 'acceptable' farms in Year 0, whereas two farms were 'not classified.' In Year 1, 16, 16 and two farms were classified as 'enhanced', 'acceptable' and 'not classified', respectively. No farm reached the category 'excellent' in any year. Overall farm classification was not further used for this analysis.

Data envelopment analysis was performed in two parts using the FEAR package (Wilson 2013) for the statistical computing software R (R Core Team 2013). First, single input-orientated bootstrapped DEA models were applied in order to calculate technical efficiency scores under CRS frontiers for both Year 0 and Year 1. Furthermore, as described above, we used the bootstrapping feature provided by the FEAR package for R (Wilson 2013) with 2,000 bootstrap iterations. Total factor productivity change from Year 0 to Year 1 was calculated with the same data set by estimating Malmquist indices. Again, following the approach proposed by Simar and Wilson (1999), bootstrapping with 2,000 replications was applied for the calculation of the bias-corrected Malmquist indices and confidence intervals (Wilson 2013). This approach ensures that the time-dependent structure of the dataset is considered in the calculation. The scores for Malmquist index and its decomposition provided in *Results* are those derived from the bootstrapping procedure.

The influence of health and welfare state on technical efficiency in Year 0 was tested using censored Tobit regression models (Tobin 1958) as efficiency scores are constrained at the upper level (Bogetoft & Otto 2011). WQ principle as well as WQ criterion scores were regressed separately on technical efficiency scores. Similarly, in a second step, multiple linear regression models using step-wise backward selection were applied to test the relationship between changes in WQ principle scores as well as WQ criterion scores and changes in technical efficiency, expressed as Malmquist indices. The WQ criteria 'Absence of prolonged thirst' and 'Absence of pain induced by management procedures' were treated as categorical variables as the respective scores are derived from decision tree classification (Welfare Quality® 2009). Scores of the WQ criteria 'Ease of movement' (all herds were kept in loose housing systems), 'Thermal comfort' (no measure has been developed yet) and 'Expression of other behaviours' (based on access to pasture, which was not provided in any farm) did not show any variation and were therefore excluded from the regression analysis. Differences in input and output factors (Table 1) between Year 0 and Year 1 were analysed using *t*-tests.

Results

On average, the farms had an efficiency score of 0.79 (± 0.11), ranging from 0.58 to 0.96 in Year 0. In Year 1, the mean efficiency score was 0.67 (± 0.12), with values ranging from 0.46 to 0.88. These mean efficiency scores indicate that farms would, on average, have to reduce their inputs by 21 and 33% to become technically efficient in Year 0 and Year 1, respectively. According to the results of the bootstrapping procedure, no farm was identified as fully efficient (ie fully efficient with regard to all three inputs) in the present sample in any of the two years.

Out of the four WQ principles, only the principle scores for 'Good health' were significantly positively associated with technical efficiency scores in Year 0 (Figure 2). An increase of ten points in the WQ principle 'Good health' caused technical efficiency scores to increase by 5 percentage points. More specifically, both the WQ criteria 'Absence of injuries' and 'Absence of disease', which both contribute to the principle 'Good health', were positively associated with technical efficiency with a less pronounced effect of the criterion 'Absence of disease' compared to 'Absence of injuries' (Table 3). At the criterion level, fewer agonistic interactions (depicted as a high score in 'Expression of social behaviour') were significantly related to higher technical efficiency scores. Furthermore, a higher score for 'Absence of prolonged thirst' was negatively associated with technical efficiency (Table 3).

Across all farms, the mean Malmquist index was 1.02 (± 0.10), thus indicating a stable situation with regard to technical efficiency. Decomposition of the Malmquist index showed that across all farms the efficiency change component increased (1.11 [± 0.13]), whereas the mean technology change decreased (0.93 [± 0.09]). The differences in WQ scores between Year 1 and Year 0 (both at principle as well at criterion level), ie changes in the welfare state, were however not associated with the farms' Malmquist index, as well as efficiency change and technology change components.

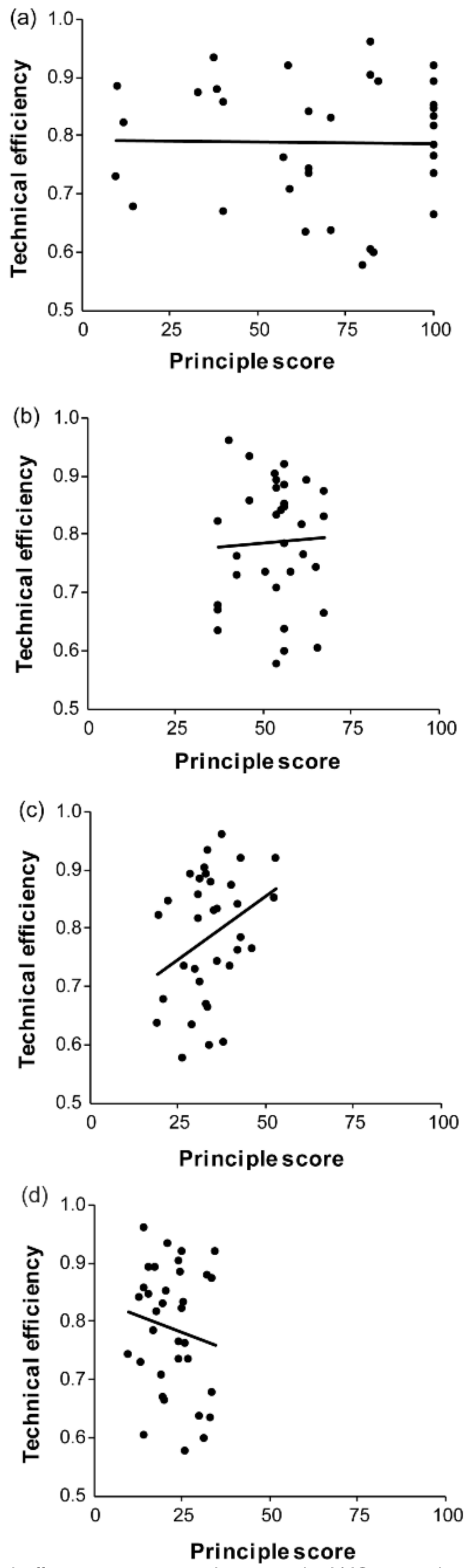
Discussion

The average bias-corrected technical efficiency scores were lower than non-corrected scores (data not shown) because efficiency scores can be overestimated when the bootstrapping procedure is not applied (Simar & Wilson 1998). Due to differences in dairy production systems and respective samples of farms, a direct comparison to DEA technical efficiency scores obtained in other studies is not appropriate. However, in the present study, technical efficiency scores for both years ranged in the order of magnitude as recently reported by Barnes *et al* (2011) and Kelly *et al* (2012b) for dairy farms in Scotland and the Republic of Ireland, respectively.

The positive correlation of the WQ principle 'Good health' and technical efficiency reflects the fact that herds with higher health states have higher milk yields, may have to spend less on treating animals or may have less (direct and indirect) yield losses that arise from poor health states. In particular lameness, which contributes to the criterion 'Absence of injuries', poses a major health issue in dairy cattle (median prevalence of lame cows in Year 0: 37%, min 13%, max 69%) and is responsible for treatment costs (Bruijnis *et al* 2012), reduced fertility (Hernandez *et al* 2001) or reduced milk yield (for a review, see Huxley 2013). Farms with higher levels of lameness might therefore face higher costs and reduced milk yields.

Compared with the criterion 'Absence of injuries', the criterion 'Absence of disease' had a smaller effect on technical efficiency, which could be due to the fact that some of the indicators associated with 'Absence of disease' do not necessarily reflect health problems which require treatments (eg nasal discharge mostly not indicating pneumonia but light irritations of the upper respiratory tract as any form of discharge is taken into account) or cannot be reliably assessed using spot observations (eg vulvar

Figure 2



Technical efficiency scores in relation to the WQ principle scores for (a) Good feeding, (b) Good housing, (c) Good health, and (d) Appropriate behaviour in Year 0 of Austrian dairy farms (n = 34).

Table 3 Tobit regression estimates of WQ criterion scores on technical efficiency scores in Year 0 for Austrian dairy farms (n = 34).

Variable†	Description	Estimate	SE	Significance
Intercept		0.502	0.140	$P < 0.001$
C1 (P1)	Absence of prolonged hunger	–0.001	0.001	ns
C2 (P1)	Absence of prolonged thirst (score of 32)‡	–0.115	0.066	$P < 0.1$
	Absence of prolonged thirst (score of 60)‡	–0.128	0.061	$P < 0.05$
	Absence of prolonged thirst (score of 100)‡	–0.163	0.053	$P < 0.01$
C3 (P2)	Comfort around resting	–0.001	0.001	ns
C6 (P3)	Absence of injuries	0.006	0.001	$P < 0.001$
C7 (P3)	Absence of disease	0.002	0.001	$P < 0.1$
C8 (P3)	Absence of pain induced by management procedures (score of 28)‡	–0.143	0.100	ns
	Absence of pain induced by management procedures (score of 52)‡	–0.132	0.090	ns
C9 (P4)	Expression of social behaviours	0.003	0.001	$P < 0.001$
C11 (P4)	Good human-animal relationship	0.002	0.001	ns
C12 (P4)	Positive emotional state	–0.001	0.001	ns

† Welfare Quality® criteria (C) contributing to Welfare Quality® principles (P);
‡ Score categories as obtained by the farms studied following Welfare Quality® (2009).

discharge). Furthermore, in the WQ protocol, udder health problems are taken into account as the percentage of animals with a somatic cell count above 400,000 cells per ml milk. This parameter has a low weight and thus only small effects on the 'Absence of disease' scores (De Vries *et al* 2013) and might therefore not fully reflect the costs associated with udder health problems. The criterion 'Pain induced by management procedures' reflects the procedures used for disbudding of calves or dehorning of adult cows. This is welfare relevant for calves but less so for cows, as very few were dehorned on the farms in this study. Long-term effects of pain induced by management procedures on milk yield have not yet been studied.

Apart from 'Good health', no other WQ principles were associated with technical efficiency. The principle 'Good feeding' comprises the prevalence of very lean animals and resource-based measures of water provision. However, very lean cows were seldom observed on the farms (median prevalence of very lean cows in Year 0: 2.9%, min 0%, max 19.4%). Thus, the principle score 'Good feeding' is mainly determined by the provision of water. However, the seemingly paradoxical association of a higher score for the criterion 'Absence of prolonged thirst', ie reflecting the provision of more drinker space and clean drinkers, with lower technical efficiency scores remains difficult to interpret. The large impact of this criterion on principle scores regarding 'Good feeding' has, however, been criticised for not validly reflecting the welfare impact of sub-optimal water provision (De Vries *et al* 2013) which may explain the lack of a meaningful relationship between water provision and technical efficiency. The majority of scores for the principle 'Good housing' ranged above 50, thus indicating a reasonably good situation where significant associations with farm efficiency may not be expected. A lack of effect at the 'Appropriate behaviour' principle level may be due to relatively little variation in the principle scores (min 9, max 34). At the criterion level, increased head butts and displacements can be a result of competition for resources, such as water, food, or lying space (DeVries & von Keyserlingk 2006). Agonistic behaviour may therefore have a detrimental effect on milk yield as reported by Rouha-Mülleder *et al* (2010).

The results indicate no relationship between the mean Malmquist index and differences in WQ scores between Year 1 and Year 0. There might be a number of reasons for this result. First, the study period of approximately one year was rather short compared to the periods used in other DEA studies (Latruffe *et al* 2012; Allendorf & Wettemann 2015). Due to the experimental character of our study it was not possible to consider a longer time-period. Studies that rely on farm accounting data (eg Allendorf & Wettemann 2015) benefit from the possibility of using data from several years, which allows them to reduce the influence of single years on farm efficiency results. However, they lack the clear advantage of integrating empirical data directly reflecting welfare states. Furthermore, the changes in WQ scores in our study (Table 1) might have been too small to exert a significant effect on farm efficiency. Minor changes in welfare state may be due to the short time-frame between the farm visits (Tremetsberger & Winckler 2015). Longer monitoring periods would have allowed farmers to implement more

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intervention measures or the interventions to exert a more pronounced effect on animal welfare. Marked increases or declines in WQ scores from Year 0 to Year 1 were mainly observed for the WQ principles 'Good feeding' and 'Good housing.' Based on the weak relationship between these two WQ principles and technical efficiency (see Tobit-regression results above; Table 3), we did not expect a significant influence of improvements or deteriorations of these areas on changes in efficiency. On the other hand, Tobit regression analysis revealed a positive relationship between principle scores for 'Good health' and technical efficiency for Year 0. However, although in the present study health and welfare planning enhanced udder health and cleanliness (Tremetsberger *et al* 2015), the changes in the scores for this WQ principle (Year 0 to Year 1) were smaller than those observed for 'Good feeding' and 'Good housing.' The observed shift in the WQ principle 'Good health' might not have been sufficient to exert clear effects on farm efficiency. Furthermore, it should be emphasised that improvements in some criterion or principle scores could be hidden by deteriorations in other areas, or *vice versa*. For instance, a farm improving in leg health (criterion 'Absence of injuries') but at the same time deteriorating in udder health (criterion 'Absence of disease') may not show changes in the respective aggregated principle score 'Good health.'

Animal welfare implications and conclusion

This study considered on-farm health and welfare assessment outcomes and technical efficiency measures in data envelopment analysis. Our results show that some areas of health and welfare of dairy cows affect technical efficiency, which emphasises the fundamental importance of animal welfare for the economic performance of farms. Since animal welfare is not only of societal interest, but also of considerable relevance for the farmers, economic consequences of improving animal welfare should be integrated more explicitly into the communication with farmers on animal welfare interventions.

However, the results of our study also show a clear need for future research. Firstly, our analysis was limited with regard to capturing the effects of animal welfare management measures on technical efficiency. Mainly due to data restrictions, we were not able to analyse the underlying factors and interlinkages steering such changes; future studies should contribute to a better understanding of these mechanisms. Furthermore, future studies should aim at covering longer time-periods. This would allow even accounting for effects of such measures, which exert their impact only in the long run often connected with adopting new techniques on the farms.

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