ECONOMIC DISCUSSION PAPERS

Efficiency Series Paper 5/2016

Animal health indicators and technical efficiency in milk production: A stochastic frontier analysis for Spanish dairy farms

Jose Antonio Pérez, David Roibás, Alan Wall

Departamento de Economía

Universidad de Oviedo

Available online at: http://economia.uniovi.es/investigacion/papers

Animal health indicators and technical efficiency in milk production: A stochastic frontier analysis for Spanish dairy farms✧

Jose Antonio Pérez,[a, 1] David Roibás,[a, 2] Alan Wall[a, 2]

[a] Oviedo Efficiency Group, University of Oviedo.
[1] Department of Accounting, School of Economics and Business, University of Oviedo, 33006 Oviedo.
[2] Department of Economics, School of Economics and Business, University of Oviedo, 33006 Oviedo.

Abstract

Health and reproductive disorders have been found to reduce milk yields in dairy cows. We combine information from two different sources to create an unbalanced panel data set of 214 dairy farms in northern Spain observed over the period 2006-2014 which includes data on production variables and health and reproduction indicators. We use this data to estimate a stochastic production frontier where the somatic cell count and the calving interval are included as determinants of technical efficiency. Higher somatic cell counts and longer calving intervals are found to decrease technical efficiency, translating into significant losses in revenue. In a simulation exercise, we find that a representative farm which reduced the values of these indicators from their median sample values to their first quartile values would increase its revenue by 13%.

Keywords Animal health, somatic cell count, dairy farms, technical efficiency, panel data, stochastic frontiers.

JEL classification: C40, D22, Q12.

✧ This research was partially funded by the Government of the Principality of Asturias and the European Regional Development Fund (ERDF)

1. Introduction

Illnesses among dairy cows and the reproductive practices to which they are subjected affect their welfare, which in turn will have effects on the productive performance of dairy farms. The relationships between animal welfare indicators and productivity has been widely studied in the veterinary science and animal science literatures. Animal welfare has several facets, both physical and psychological, and several indicators can be used depending on the aspect being studied. One of the most accepted broad definitions of animal welfare is ‘the state of an animal as it attempts to cope with its environment’ (Fraser and Broom, 1990), which clearly includes illnesses and reproductive practices. Whereas veterinary scientists have traditionally tended to take an ‘animal-based’ approach to welfare, focusing on animal physiology, behaviour and pathologies (see, for example, Hewson, 2003), economists will tend to take a ‘human-based’ approach which also takes into account education, beliefs, culture, income and experience when attempting to determine the optimal level of animal welfare (McInerney, 2004). As an example of the economist’s human-based approach, McInerney (2004) put forward a conceptual framework for analysing the relationship between dairy cow welfare and productivity by proposing a production possibilities frontier that implied a trade-off in the sense that increases in animal welfare could only be achieved at the expense of reduction in their productivity. However, this trade-off implies that dairy farms are producing in a technically efficient manner. If they are not, then the possibility arises of increasing both animal welfare and productivity through increases in technical efficiency.

Our work aims to contribute to the literature on the relationship between animal welfare and productivity by analysing the relationship between productive performance, measured with estimates of technical efficiency, and indicators of health and reproductive practices for a panel of Spanish dairy farms. In particular, we use data on dairy farms in the northern Spanish region of Asturias from two sources to construct a panel of 108 farms observed over the period 2006-2014 which combines production variables (inputs and outputs) with the health and reproductive practice indicators. The health indicator we use is the somatic cell count, while the indicator for reproductive practices is the calving interval. The somatic cell count (SCC) in milk is an indicator of the general state of health of the mammary glands of milking cows. High levels of SCC are associated with mastitis, a common illness among dairy cows, and lower quality of milk, even rejection of the milk by distributors (Huijps et al., 2008; Pritchard et al. 2013).

As an indicator of health of the herd, the SCC may reflect sub-optimal management on the part of the farmer and we would expect a negative relation between SCC and technical efficiency. The calving interval is an indicator of the reproductive practices of the herd, and reduced reproductive performance has been found to lower the quantity of milk produced per cow (Lawson et al., 2004b). We use these data to estimate a stochastic production frontier where the animal welfare indicators are included as determinants of technical inefficiency. Our results show that our animal welfare indicators affect technical inefficiency, and we quantify these effects with a simple simulation analysis.

The paper proceeds as follows. In the next section we provide a brief review of the literature on the relationship between animal welfare and productivity, with particular emphasis on the literature using frontier-based techniques to study dairy farms. Section 3 describes the data used. In Section 4 we present the emirical model to be estimated and the results. Section 5 concludes.

2. Dairy cow welfare and productivity: A brief review of the literature

Several studies have addressed the relationships between the welfare of dairy cattle and productivity.[1] Von Keyserlingk et al. (2009) argue that a low level of animal welfare can lead to low productivity, citing a series of studies that show how different types of illnesses and stress can lead to low milk yields. In accordance with the conceptual framework provided by McInerney (2004), on the other hand, high cow productivity may be associated with low levels of animal welfare if farmers are producing efficiently. One of the reasons for this positive relationship is the genetic selection of cows with the aim of achieving higher yields, which has been found to be correlated with health problems such lameness, mastitis, fertility problems reduced and lower longevity (Oltenacu and Algers, 2005). A good overview of the relationship between genetic selection criteria and health and reproductive problems among dairy cattle can be found in Pritchard et al. (2013).

[1] At a more general level, Lusk and Norwood (2011) discuss how production economics, welfare economics and consumer theory can contribute tothe debate about anilam welfare.

Halasa et al. (2007) carry out a review of studies that attempt to quantify the economic effects of mastitis and conclude that milk production losses due to mastitis are directly related to the somatic cell count (SCC). Huijps et al. (2008) quantify economic losses due to mastitis for a sample of Dutch dairy farms, and find that the majority of farmers underestimate these economic losses. With regard to calving intervals, Dono et al. (2013) analyse a sample of 50 Italian dairy farms, whcih they divide into two production systems based on a clustering. They find that the the most productive system was characterised by shorter calving intervals and a more efficient use of feed.

While there abundant literature in the veterinary and animal sciences on the relation between the management of animal health and reproduction and milk production, the economic literature is much smaller and few studies have used frontier techniques. Lawson et al. (2004a,b) used stochastic frontier analysis to study the effects of a series of illnesses and reproductive disorders on the technical efficiency of Danish dairy farms. The adverse effects of reproductive disorders on milk production were found to be compensated by good managerial decisions in efficient farms. Calving intervals were one of the reproductive indicators used, but it was not found to have an effect on efficiency. Hansson and Öhlmér (2008) used Data Envelopment Analysis (DEA) to analyse the effects of animal breeding, health and feeding practices for Swedish dairy farms, finding that breeding practices influenced efficiency but that the sample was already quite homogeneous in terms of health practices so that these did not have scope to provide further efficiency gains. Also using DEA, Hansson et al. (2011) analysed the effects of preventative measures against mastitis on dairy farm efficiency, identifying measures that increased efficiency when SCC scores were found to be too high. The relation between lameness and technical efficiency was analysed by Barnes et al. (2011) for a sample of British dairy farms usins DEA. Finally, Allendorf and Wettemann (2015) investigated how a series of animal welfare indicators affected the technical efficiency of German dairy farms using DEA and a censored regression model. They found, among other results, that a longer calving interval had a negative effect on technical efficiency whereas a higher somatic cell count had a positive effect on technical efficiency. They explain the counterintuitive latter result as probably being due to the fact that in their sample they had only two observations out of 575 which had somatic cell counts above the level at which milk would be classified as lower quality and price penalties imposed.

3. Data

The empirical application is carried out using data from dairy farms located in the region of Asturias in northwest Spain, one of main milk-producing regions in the country. The data used in the empirical analysis consists of an unbalanced panel of 1,256 observations corresponding to 214 dairy farms observed during a 9-year period from 2006 to 2014.[2] Two data sets are combined to form this panel, which includes production data (inputs and output) and determinants of inefficiency.

First, production data (inputs and outputs), as well as some determinants of inefficiency involving farm characteristics, come from a voluntary record-keeping programme in which these farms were enrolled. This record-keeping program is conducted by the regional government and gathers information on nine Dairy Farmer Management Associations (AGELES[3]) located in the region. The main objective of these associations, which are funded by the regional government, is to provide management advice to their affiliates. Each farm is visited on a monthly basis by a technical expert in order to collect the data necessary for the managerial advisory service, and this monthly information is then combined with annual inventories to prepare an annual report on each farm.

Second, the data for the animal health indicators which we use, and which constitute the two remaining inefficiency determinants, were provided by a breeder's cooperative, ASCOL.[4] ASCOL, founded in 1986, is a cooperative with over 1,000 milk producers affiliated that specialises in genetic selection services for its members. The cooperative provides high-quality data on, among other variables, somatic cell counts and calving intervals and we have been able to cross this information with the production data.

In our empirical model we will use one output, six inputs, and five determinants of inefficiency (three related to farm characteristics and two health indicators). The dependent variable in the (stochastic frontier) model is *milk*, which represents milk production and is measured in litres. The six inputs are as follows: *labour*, which includes family labour and hired labour and which is measured using Social Security expenses;

---

[2] These are specialized dairy farms, with milk accounting for over 90% of sales revenues.
[3] Agrupaciones de Gestión de Explotaciones Lecheras (Dairy Farm Management Associations).
[4] *Asturiana de Control de Leche* (Asturian Milk Control Cooperative).

cows, defined as the number of adult cows in the herd;[5] *concfeed* is the amount of concentrate feed used by the farm, measured in kilograms; *forageprod* is expenditure on forage production, defined as the costs of seeds, fertilizer, fuel, land, other raw materials, and machinery hire and amortization; *foragebought* is defined as expenditure on the acquisition of forage; and *animalexpend* represents animal expenditure, which includes expenditure on veterinary services, milking, electricity, water and the amortization of buildings and technical installations.[6] All the monetary variables are expressed in 2014 euro, where the CPI has been used as a deflator.

The determinants of inefficiency are divided between farms characteristics and health indicators. The farm characteristics are *conc/cow*, which is the ratio of concentrate feed to cows and controls for the level of intensification of the farm; *ownland/totland* is the ratio of owned land to total land; finally, *famlab/totlab* is the ratio of family labour to total labour. The health indicators, from ASCOL, are the somatic cell count (*SCC*) and the calving interval (*interval*). The calving interval measures the average number of days since the last birth. To calculate the somatic cell count, monthly reports are carried out for each farm that contain somatic cell counts for all milking cows. The cell count in these reports is a weighted average by litres of milk per cow, and the annual figure for each farm is calculated as the geometric mean of the individual values of each control. It should be noted here that data on the somatic cell count are available from the AGELES database. However, this data has the drawback that it is calculated from the somatic cells contained in the milk that is supplied to the distributors and therefore does not take into account the milk that has been discarded due to excessively high somatic cell counts in certain cows at given points in time. The data provided by ASCOL, on the other hand, is based on analyses carried out on each individual cow in the herd, and therefore represents a much more reliable indicator of the state of health of the herd than the cell count calculated based on the milk supplied to the distributors.

Descriptive statistics of the production variables and inefficiency determinants are provided in Table 1. Differences among farms are quite large as the standard deviation of milk production is 75% of the mean production. The average farm size in the sample

---

[5] All the farms in the sample use Holstein-Frisian cows.

[6] The use of the categories *forage production expenses* and *animal expenses* as inputs can also be found in Roibás and Alvarez (2012), Orea et al. (2015) or Alvarez and Arias (2015), among others.

of 55 cows is substantially larger than the average Spanish farm (31 cows in 2010; Eurostat, 2015) and also larger than the average farm size in some of the main milk producing countries in Europe such as France or Germany (46 cows; Eurostat, 2015). Moreover, restructuring in recent years has led to a continual increase in farm sizes in the region.

Table 1: Descriptive statistics

Variable	Description	Mean	Std. Dev.	Min	Max
Output					
Milk	Milk production (litres)	463,767	346,379	49,098	3,548,764
Inputs					
Labour	Social Security expenditure (€)	5,377	3,370	87	54,413
Cows	Cows (number)	55	35	11	325
Concfeed	Concentrate feed (kg)	215,648	167,426	5,770	1,426,382
forageproduced	Forage production expenditure (€)	32,438	25,291	3,061	205,643
foragebought	Forage purchases (€)	11,070	15,471	12	180,557
animalexpend	Animal expenditure (€)	22,423	18,215	1,325	230,937
Inefficiency determinants					
SCC	Somatic cell count (1,000s/ml)	298	125	64	776
Interval	Calving interval (days)	432	28	370	617
conc/cow	Concentrate feed/Cow	3827	1522	102	18759
ownland/totland	Own Land/Total Land	0.55	0.29	0.00	1.00
famlab/totlab	Family Labor/Total Labor	0.86	0.26	0.00	1.00

4. Empirical model and results

To estimate technical efficiency and its determinants, we specify a translog functional form for the stochastic production frontier and follow Caudill et al. (1995) by allowing the determinants of inefficiency to affect the variance of the inefficiency term. The empirical model to be estimated is:

$$\ln y_{it} = \alpha_i + \sum_{j=1}^{6} \beta_j \ln x_{jit} + \frac{1}{2} \sum_{j=1}^{6} \sum_{k=1}^{6} \beta_{jk} \ln x_{jit} \ln x_{kit} + \sum_{t=2007}^{2014} \alpha_t D_t + v_{it} - u_{it} \qquad (1)$$

where v_{it} is the symmetric random error term which we assume normally distributed with mean zero, and $u_{it} \geq 0$ is a one-sided error term capturing technical inefficiency. This is assumed to follow a half-normal distribution, i.e., $u_{it} \sim N^{+}(0, \sigma_{uit}^2)$, and the variance of u_{it} is specified as $\sigma_{uit}^2 = g(z_{it}; \delta)$ where z represents the explanatory variables and δ is a set of parameters to be estimated (Caudill *et al.* 1995).

The estimates for the production frontier are reported in Table 2 (values of the individual effects are not reported). All first-order input terms are positive and highly statistically significant with the exception of labour.[7] Summing these parameters, we find slightly decreasing returns to scale (scale elasticity = 0.965). A test of the hypothesis of constant returns to scale yielded a *p*-value of 0.091, thereby rejecting constant returns at the 10% level of significance. Finally, the yearly dummy variables were all negative and significant, implying technical regress throughout the sample period with respect to the base year.

Table 2: Frontier parameter estimates

Variable	Coef.	t-stat.	Variable	Coef.	t-stat.
labour	-0.006	-0.66	concfeed × forageproduced	0.013	0.51
cows	0.616	24.71	concfeed × foragebought	0.001	0.10
concfeed	0.199	12.66	concfeed × animalexpend	0.065	2.09
forageproduced	0.056	5.10	forageproduced ^{2}	0.083	3.02
foragebought	0.012	2.96	forageproduced × foragebought	0.010	1.60
animalexpend	0.089	6.98	forageproduced × animalexpend	-0.050	-2.07
labour^2	0.003	0.37	foragebought ^{2}	0.002	0.81
labour×cows	-0.012	-0.32	foragebought × animalexpend	-0.005	-0.77
labour×concfeed	0.008	0.39	animalexpend ^{2}	0.112	3.23
labour × forageproduced	0.021	1.50	D_{2007}	-0.052	-6.00
labour × foragebought	0.007	1.31	D_{2008}	-0.103	-10.10
labour × animalexpend	-0.008	-0.42	D_{2009}	-0.079	-7.99
cows^2	0.683	8.08	D_{2010}	-0.047	-4.87
cows × concfeed	-0.355	-7.93	D_{2011}	-0.078	-7.53

[7] This is a common result in studies of dairy farms where family labour represents a high proportion of total labour (see, e.g., Cuesta, 2000). From Table 1, it can be seen that, on average, family labour accounts for 86% of total labour.

cows × forageproduced	-0.045	-1.11	D_{2012}	-0.084	-8.02
cows × foragebought	-0.007	-0.57	D_{2013}	-0.092	-8.23
cows × animalexpend	-0.189	-4.03	D_{2014}	-0.038	-3.12
$concfeed^2$	0.216	6.34			

Dependent variable: milk production.
N = 1,256
All variables expressed in logs.
Log. Likelihood = 1,497.33

The estimates of the determinants of technical efficiency are reported in Table 3. All explanatory variables were found to be significant except for the ratio of family labour to total labour. Of most relevance to the objectives of this study, the SCC and calving intervals were found to be highly significant and positively related to technical inefficiency.

Table 3: Estimates of technical efficiency determinants

Variable	**Coef.**	**t-stat.**
Constant	-17.993	-2.14
ln SCC	0.632	2.91
ln interval	3.122	2.30
ln conc/cow	-1.346	-3.31
ownland/totland	1.464	3.63
famlab/totlab	0.572	1.10

Dependent variable: $\ln \sigma_u^2$

The average technical efficiency scores were calculated using the formula (Kumbhakar and Lovell, 2000):

$$E[\exp(-u_{it})] = 2[1 - \Phi(\sigma_u)] \exp\left(\frac{\sigma_u^2}{2}\right) \quad (2)$$

and descriptive statistics for each year are reported in Table 4. Average technical efficiency for the whole sample was around 0.94 each year, ranging from a low 0.756 to a maximum of 0.985.

Table 4: Estimates of technical efficiency (expected values)

Year	Mean	Std. Dev.	Min.	Max.
2006	0.942	0.023	0.809	0.985
2007	0.942	0.025	0.756	0.975
2008	0.938	0.021	0.839	0.975
2009	0.939	0.021	0.848	0.982
2010	0.941	0.021	0.861	0.977
2011	0.941	0.023	0.848	0.985
2012	0.942	0.021	0.851	0.983
2013	0.941	0.025	0.830	0.983
2014	0.945	0.025	0.771	0.983
Overall	*0.941*	*0.023*	*0.756*	*0.985*

To gain further insight into the influence of the health and reproductive indicators on productive performance, we carry out a simple simulation analysis using the estimated parameters from the empirical model. We begin by calculating the expected efficient production level (y^*) of the representative farm, defined as the farm with inputs set equal to their sample mean values and the constant term set equal to the average of the individual effects. To measure the impact of SCC on technical efficiency and, by extension, on production, we calculate the expected technical efficiency index for the representative farm, defined as the farm that has values of the determinants of efficiency other than SCC (i.e., *interval*, *conc/cow*, *ownland/totland*, *famlab/totlab*) equal to their sample mean values. SCC is then set equal to its observed value for each observation, thereby generating a value of expected technical efficiency for the representative farm for each of the values of SCC observed in the sample. To convert the impact of changes in SCC into euro, we take the average price of milk in the last year of the sample, 2014, as a reference. The average price of milk received was 0.373€/litre. Multiplying the predicted output levels by the price gives us the total revenue of the representative farm for each sample value of SCC. The relationship between expected revenue and SCC is plotted in Figure 1. We carry out the same exercise for the calving interval (noting that this time the representative farm has values of the determinants other than *interval* equal to their sample means) and plot the corresponding relationship between total revenue and the calving interval in Figure 2.

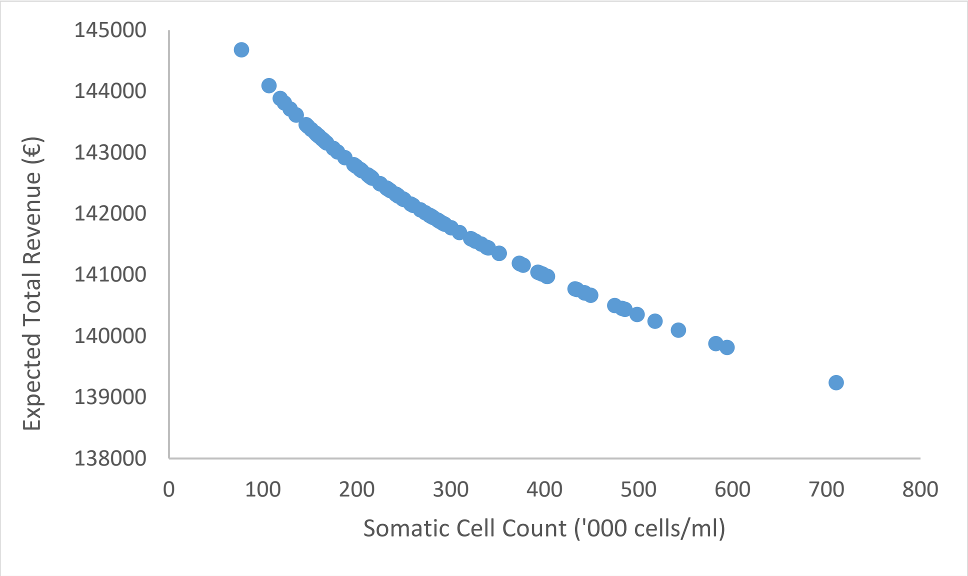

Figure 1. Relation between expected revenue (year 2014 €) and somatic cell count

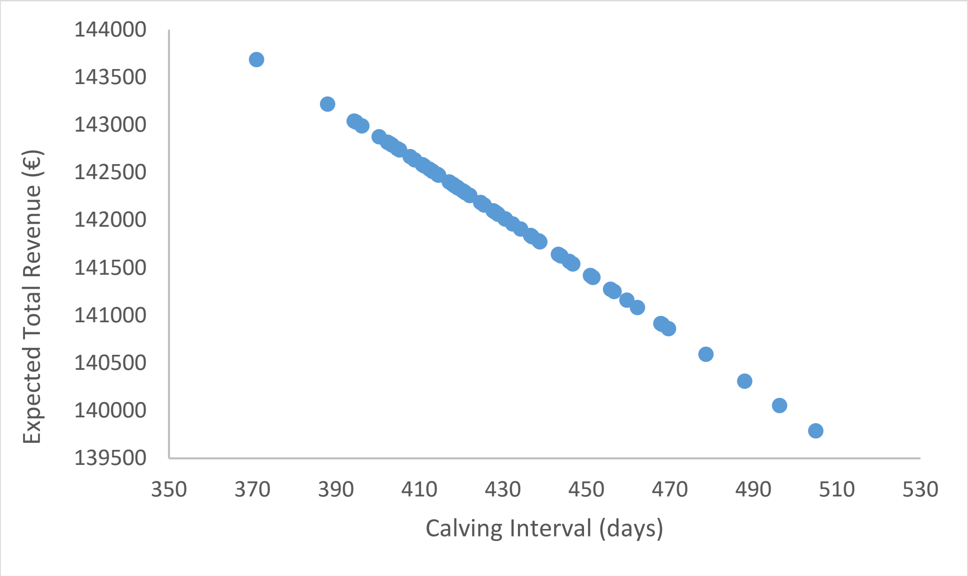

Figure 2. Relation between expected revenue (year 2014 €) and calving interval

As can be seen, the variations in total revenue are quite substantial over the sample range of the health and reproductive indicators. In particular, as we go from the minimum to maximum observed SCC values, expected total revenue for the representative farm varies from €150,817 to €117, 169, a drop of 22.3%. For the calving interval, expected revenue falls from €149,195 to €117,034, a decrease of 21.6%. While here we are going from extreme to the other of the observed values of the SCC and calving interval indicators, substantial changes in revenue can also be found for more modest changes in observed values. In Table 5, we present the expected total revenue for the representative farm corresponding to the first and second quartile values of SCC (TR_{SCC}) and the calving interval (TR_{INT}).

Table 5: Changes in total revenue for different values of health and reproductive indicators

Quartile	SCC	TR_{SCC}	Interval	TR_{INT}
Q1	208	143,319	414	142,787
Q2	278	126,744	429	126,528
$\Delta \boldsymbol{TR}(\mathbf{Q2} \rightarrow \mathbf{Q1})$: €		16,574		16,259
$\Delta \boldsymbol{TR}(\mathbf{Q2} \rightarrow \mathbf{Q1})$: %		13.1		12.8

The last two rows show the absolute and percentage changes in expected total revenue when the values of SCC and the calving interval decrease from their second quartile (median) value to their first quartile value. As can be seen, if farms could change their practices to achieve these first quartile values, they would generate an additional 13% in total revenue.

5. Conclusions

We have analysed the effect of two indicators of animal welfare on technical efficiency for a sample of 214 Spanish dairy farms observed over the period 2006-2014. Using stochastic frontier analysis techniques, we estimated a stochastic production frontier where the somatic cell count and the calving interval, indicators of animal health and reproductive practices respectively, are modelled as determinants of technical efficiency. Increased values of both variables are found to reduce technical efficiency. We quantify the losses in revenue for the representative farm caused by high values of these indicators and find them to be substantial. In particular, if the indicators decrease from their median values to their first quartile values, total revenues of approximately 13% could be achieved. This points to clear incentives to reduce the incidence of mastitis and to improve reproductive practices.

References

Allendorf, J.J. and Wettemann, P.J.C. (2015). Does animal welfare influence dairy farm efficiency? A two-stage approach. *Journal of Dairy Science* 98:1–11.

Bach, A., Valls, N., Solans, A. and Torrent, T. (2008). Associations between non-dietary factors and dairy herd performance. *Journal of Dairy Science* 91: 3259–3267.

Barnes, A.P., Rutherford, K.M.D., Langford, F.M. and Haskell, M.J. (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: 5449-5457.

Cuesta, R. A. (2000). A production model with firm-specific temporal variation in technical efficiency: with application to Spanish dairy farms. *Journal of Productivity Analysis* 13: 139-158.

Dono, G., Giraldo, L. and Nazzaro, E. (2013). Contribution of the calving interval to dairy farm profitability: results of a cluster analysis of FADN data for a major milk production area in southern Italy. *Spanish Journal of Agricultural Research* 11(4): 857-868.

Farm Animal Welfare Council (FAWC) (2007). *Report on stockmanship and farm animal welfare*. Report submitted to Defra.

Fraser, A. F. and Broom, D. M. (1990). *Farm animal behaviour and welfare*. Saunders, New York.

Halasa, T., Huijps, K., Osterds, 0. and Hogeveen, H. (2007). Economic effects of bovine mastitis and mastitis management: A review. *Veterinary Quarterly* 29(1): 18-31.

Hansson, H. and Ohlmer, B. (2008). The effect of operational managerial practices on economic, technical and allocative efficiency at Swedish dairy farms. *Livestock Science* 118: 34–43.

Hansson, H., Szczensa-Rundberg, M. and Nielsen, C. (2011). Which preventive measures against mastitis can increase the technical efficiency of dairy farms? *Animal* 5: 632–640.

Hewson, C. J. (2003). What is animal welfare? Common definitions and their practical consequences. *Canadian Veterinary Journal* 44: 496–499.

Kumbhakar, S. C. and Lovell C.A.K. (2000) *Stochastic frontier analysis*. Cambridge University Press, Cambridge.

Lawson, L.G., Aggerb, J.F., Lunda, M., Coelli, T. (2004a). "Lameness, metabolic and digestive disorders, and technical efficiency in Danish dairy herds: A stochastic frontier production function approach." *Livestock Production Science* 91:157–172.

Lawson, L.G., Bruun, J., Coelli, T., Agger, J.F. and M. Lund (2004b). Relationships of Efficiency to Reproductive Disorders in Danish Milk Production: A Stochastic Frontier Analysis. *Journal of Dairy Science* 87:212–224.

Lusk, J.L. and Norwood, F. B. (2011). Animal welfare economics. *Applied Economic Perspectives and Policy* 33(4): 463-483.

McInerney, J.P. (2004). *Animal welfare, economics and policy*. Report prepared for Defra.

Oltenacu, P. A. and Algers, B. (2005). Selection for increased production and the welfare of dairy cows: Are new breeding goals needed? *Ambio* 34: 311-315.

Pritchard, T. Coffey, M., Mrode, R. and Wall, E. (2013). Genetic parameters for production, health, fertility and longevity traits in dairy cows. *Animal*, 7:1: 34–46.

Von Keyserlingk, M.A.G. Rushen, J. de Passillé, A.M. and Weary, D.M. (2009). The welfare of dairy cattle: Key concepts and the role of science. *Journal of Dairy Science* 92: 4101–4111.

Webster, J. (1995). *Animal welfare: A cool eye towards Eden*. Blackwell Science, Oxford.