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Exploring the economic potential of reducing broiler lameness

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ABSTRACT

1. The present study was designed first to explore the potential economic benefits of adopting management practices to reduce lameness in broiler farms, and second to explore farmers' possible perceptions of this potential in the Swedish context. The likely financial effects were addressed using a normative economic model, whereas a questionnaire-based survey was used to obtain in-depth knowledge about the perceptions of a group of broiler farmers in Sweden.
2. The three alternative practices (out of 6 tested) which realised the greatest improvements in gross margin and net return to management compared to the conventional practice were feeding whole wheat, sequential feeding and meal feeding.
3. The model showed that the negative effect of feeding whole wheat on feed conversion rate was outweighed by the effect of a low feed price and the associated decrease in feed costs. The price of wheat played a major role in the improvement of economic performance, whereas the reduction of lameness itself made a relatively minor contribution.
4. Apparently, the surveyed farmers do not recognise the potential of the positive effects of changing feed or feeding practices on both broiler welfare and farm economics although their implementation can be of great importance in the broiler sector where profit margins are very tight.

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Animal welfare; broiler production; economic performance; farmers' perception; lameness

Introduction

Most broiler chickens produced for commercial purposes worldwide have a fast growth rate and are reared in intensive, confined systems with high stocking densities (Knowles *et al.*, 2008). Lameness in broilers is generally considered a consequence of the genetic selection for rapid growth rate (Bradshaw *et al.*, 2002) and is often associated with an impaired walking ability. The latter can be measured using a gait score (GS) which is expressed in 6 categories ranging from completely normal (0) to immobile (5) (Kestin *et al.*, 1992). A cross-sectional study including French, British, Dutch and Italian broiler flocks reared in traditional, indoor farm systems suggested that the average prevalence of lameness was 15.6%, measured by the percentage of chickens with a GS ≥3 (Bassler *et al.*, 2013). In a study using the Welfare Quality broiler assessment protocol (Welfare Quality®, 2009) in Dutch (majority of the flocks), British, Belgian and Italian flocks, an average 57% of the birds in flocks with standard, fast-growing strains had a GS ≥3, whereas this fell to 17% of birds in flocks with alternative, slower growing strains (De Jong *et al.*, 2011). An earlier study by Sanotra *et al.* (2003) indicated that in Sweden the prevalence of chickens with a GS ≥3 ranged from 14.1% to 26.1%.

Lameness impairs the welfare of broiler chickens in commercial broiler production (Bradshaw *et al.*, 2002), as lame birds may have difficulty in performing essential behaviours, such as gaining regular access to feeders and drinkers (Danbury *et al.*, 2000; Hall, 2001; Butterworth *et al.*, 2002; Bessei, 2006). These birds may also experience pain, though evidence on the correlations between lameness, pain and underlying pathologies is inconclusive. For example, several studies suggest that lame birds with higher GSs suffer pain when they walk (Mc Geown *et al.*, 1999; Danbury *et al.*, 2000; Buchwalder and Huber-Eicher, 2005; Naas *et al.*, 2009; Caplen *et al.*, 2014; Hothersall *et al.*, 2016), whereas others argue that the relationship between lameness and pain (Skinner-Noble and Teeter, 2009; Siegel *et al.*, 2011) and between lameness and underlying pathologies is weak (McNamee *et al.*, 1998; Sandilands *et al.*, 2011; Fernandes *et al.*, 2012). Regardless of the variation in the findings of these studies, lameness constitutes a welfare problem because it leads to compromised mobility and probably pain in at least some birds. Furthermore, lameness negatively affects productivity.

Leg abnormalities and lameness, indicated by poor gaits, are associated with higher morbidity and mortality in broiler flocks (Verma, 2007; Wideman *et al.*, 2012) and the level of lameness and the final weight at delivery are negatively related (Butterworth and Haslam, 2009). This negative impact of lameness on production most likely reduces economic performance, i.e. production costs and returns (Bradshaw *et al.*, 2002; Gocsik *et al.*, 2014). Studies of on-farm risk factors and management practices that affect gait health (Butterworth and Haslam, 2009; Bassler *et al.*, 2013) identified opportunities to improve welfare and reduce economic loss.

Steps to reduce lameness may require farmers to change production conditions and management practices that otherwise exacerbate the problem. In this context, the cost and benefits of adopting new practices may be of importance for farmers (Gocsik *et al.*, 2015). Besides the extrinsic characteristics of a new practice, psychological aspects such as farmers' perception of its relative advantage play a significant role in its adoption (Rogers, 1995; Adrian *et al.*, 2005). Hereto though, limited attention has been paid to farmers' perception of the relevance of lameness and the

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economic benefits of its reduction. In this regard, Butterworth and Haslam (2009) suggested that farmers perceive the impact of lameness on production as relatively small, which may possibly be attributed to difficulties in its detection and assessment.

The objective of this study was twofold. First, it aimed to explore the economic potential of management practices intended to reduce broiler lameness. Evaluating these management practices using real-world experiments is costly and disruptive. Hence, a normative economic model was developed to address the economic potential of these practices under Swedish conditions. This approach is often used to model potential economic performances of different farm systems and farming practices (Acs *et al.*, 2005; Kerselaers *et al.*, 2007). Model results can identify practices that merit further real-world research. Second, farmers' possible perceptions of the management changes were examined by surveying 21 Swedish broiler farmers.

Materials and methods

Normative economic model

Bioeconomic rationale of lameness

Figure 1 outlines the complex relationships between management and housing practices and lameness and the potential effect of lameness on management decisions. Housing and management practices such as lighting programmes, stocking density, diet and feeding regime, and growth rate can all influence the walking ability of broilers (Knowles *et al.*, 2008; Butterworth and Haslam, 2009; Bassler *et al.*, 2013). Walking ability of broilers is commonly assessed using a 6-point gait-scoring system with categories ranging from completely normal (0) to immobile (5) (Kestin *et al.*, 1992; Welfare Quality®, 2009). There is evidence that welfare is poor in birds with a GS ≥3 (Kestin *et al.*, 1992; Mc Geown *et al.*, 1999). Birds with a GS of 3 are considered moderately lame as they have an identifiable abnormality, which impairs their function. Birds with a GS of 4 and 5 are considered severely or completely lame, respectively (Kestin *et al.*, 1992). Hence, in the present study, prevalence of lame birds is defined as the percentage of the flock with a GS of 3, 4 or 5.

Lameness influences not only consumers' perception of bird welfare (Castellini *et al.*, 2008) but also the technical performance of the birds, such as mortality and growth rate (Knowles *et al.*, 2008). Consumers are heterogeneous in terms of their preferences with regard to the various aspects of animal welfare; this causes uncertainty in their willingness to pay for improvements in animal welfare and, hence, in farmers' income. Therefore, this study focused on evaluating the relationships between broiler lameness and the technical and economic performance of the broiler farm; the pivotal role of price premiums in the potential reduction of broiler lameness was not considered.

Technical performance affects economic performance of farms primarily through production costs. From an economic perspective, reducing lameness can be a complex issue. For example, a change in management practice intended to reduce lameness may reduce growth rate (Knowles *et al.*, 2008), hence increases feed costs per kilogram delivered chicken provided that other factors are constant. On the other hand, improved welfare might reduce mortality (Bennett *et al.*, 2002) which in turn can at least partially compensate for the increased feed costs. Moreover, the use of feed differing in composition from the regular compounded feed may reduce the price of feed and thus reduce overall feed costs (Umar Faruk *et al.*, 2010). All in all, it can be hypothesised that extra costs resulting from the implementation of practices designed to reduce lameness could, to a certain extent, be compensated for by other associated gains. A positive evaluation of the studied management practices may encourage adjustment of housing and management practices.

The farm model

To estimate the economic impact of different production practices, a partial budget-based economic farm model was developed from earlier models (Dijkhuizen and Morris, 1997; Gocsik *et al.*, 2014). In the latter study, the approach was used to calculate the economic impact of the most prevalent endemic diseases in Dutch broiler production systems. For present purposes, the technical and economic inputs were adjusted to fit the characteristics of Swedish broiler production. The economic impact of lameness is determined by the prevalence of lame birds (GS ≥3) and by its impact on productivity, and expressed in terms of financial performance indicators, such as production costs, gross margin (i.e. revenues minus variable costs) and net return to management per kilogram of delivered broiler (i.e. revenues minus variable costs minus fixed costs).

In the model, a fixed production period was assumed that corresponded to the time required to reach the average

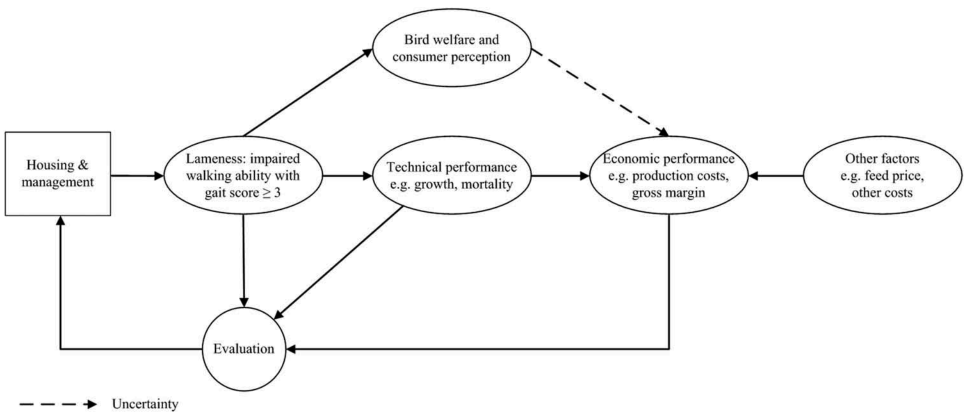

Figure 1. Bioeconomic rationale of lameness in broiler production.

live weight at delivery in the case of healthy chickens. Lame chickens, however, usually grow more slowly than healthy ones (Yalcin *et al.*, 1998), thus implying that given a fixed production period the quantity of kilogram live weight decreases because lame chickens are delivered (when still fit for transport) at a lower weight than healthy ones and because of the culling of severely lame birds. In turn, fixed costs per kilogram live weight delivered increase.

The model includes 4 factors through which lameness may influence farm productivity and, hence financial performance. These factors include increased mortality, increased feed conversion, increased condemnation rate at slaughter and decreased daily weight gain.

Increased mortality due to lameness causes financial loss. Relevant factors include the cost of starting material, i.e. d-old chick, and the lost revenue due to mortality minus the cost of delivery to the slaughterhouse. Accordingly, the cost of mortality was calculated by Equation (1):

$$\text{Cost of mortality} = \left(\text{price dayold chick} + \left(\frac{(\text{producer price} \times \text{weight at delivery}) - \text{price dayold chick}}{2}\right) - \text{cost of delivery}\right) \times \text{mortality rate} \quad (1)$$

Lame chickens were assumed to have died around the middle of the production period. Fixed costs per delivered broiler and per kilogram live weight may change because fewer chickens are delivered.

Increased feed conversion rate results in higher feed cost when other variables, e.g. final weight at delivery and the price of feed, remain constant. Extra feed costs were calculated using Equation (2).

$$\text{Extra feed costs} = \left(\frac{\text{weight at delivery}}{1000}\right) \times \text{feed conversion} \times \text{feed price} \quad (2)$$

Condemnation rate at slaughter can affect revenue, since costs were already made during the production of chickens rejected at slaughter, but due to rejections little or no revenue can be made. The cost of condemnation was calculated using Equation (3):

$$\text{Cost of condemnation at slaughter} = (\text{producer price} \times \text{weight at delivery}) \times \text{condemnation rate} \quad (3)$$

Like mortality, condemnation also affects the fixed costs per delivered broiler and per kilogram live weight because fewer birds are accepted (and paid for).

Broiler production in Sweden: conventional practice

The Swedish legislation for broiler production is stricter than the European Directive, which provides minimum rules for the protection of chickens kept for meat production in the European Union (EU) (EC Directive, 2007; Björk, 2012). Moreover, the Swedish Poultry Meat Association introduced the Swedish animal welfare programme to which 98% of broiler producers in Sweden comply (SPMA, 2015). This programme allows a maximum stocking density of 36 kg/m^2 (Björk, 2012) that is in contrast to the maximum stocking density of 42 kg/m^2 set by the EU Directive. This maximum is, however, only allowed if the farms have an adequate ventilation and heating system and if the mortality remains below 3.40% at 40 d. Broilers are on average kept for 32–35 d, and are slaughtered at a weight of 1.6–2.3 kg. Birds are housed indoors, mainly in barns with windows/inlets to provide daylight, which is not required by the EU Directive. In accordance with the EU Directive, broilers must have at least 6 h of darkness per day of which 4 h must be uninterrupted. Ross 308 and Cobb 500 make up 60% and 40% of the broiler population, respectively (Björk, 2012). The cleaning and disinfection period is 7–14 d and wood shavings are usually used as litter. The conventional practice in the present study was defined on the basis of these parameters.

Management practices to reduce lameness

The prevalence of lame birds (percentage of flock with a GS of 3, 4 or 5) and the impact on production performance are influenced by several risk factors, such as lighting programmes, stocking density, diet, feeding regime and growth rate (Knowles *et al.*, 2008; Butterworth and Haslam, 2009; Bassler *et al.*, 2013). Practices targeting these risk factors may reduce the prevalence of lameness and its impact but they might also affect the performance of the healthy birds.

An epidemiological study (Bassler *et al.*, 2013) estimated that increasing the dark period (at 3 weeks of age) from 0 to 6.5 h reduced the prevalence of lame birds from 16.9% to 7.4%. Knowles *et al.* (2008) also found that for every 1 h increase in the daily dark period across a range of 0 to 8.5 h, there was a 0.079 improvement in flock GS. Moreover, Classen (2004) suggested that increasing the dark period from 4 to 8 h decreased final weight but it also led to an improved feed conversion.

When stocking density was decreased from 455 to 625 cm^2/bird, the GS at 35 d of age was 0.195 units lower and body weight was positively affected (Sørensen *et al.*, 2000). Hall (2001) then suggested that a stocking density of 40 kg/m^2 rather than 34 kg/m^2 increased daily mortality and the incidence of leg problems, and negatively affected the birds' behaviour.

A change from *ad libitum* to meal feeding (2, 3 or 4 times a day while maintaining equal duration of feeding at 240 min/d) reduced the prevalence of leg weakness (Su *et al.*, 1999). Furthermore, Su *et al.* (1999) also reported that early feed restriction programmes had positive effect on leg weakness but this practice was less effective than meal feeding. The tested feed restriction programmes differed in starting age (5, 7 and 9 d of age), length of restriction (5 and 7 d) and levels of restriction (predetermined amounts of feed calculated to achieve 25%, 50% and 75% of the predicted growth of *ad libitum* birds during the restriction period).

Sequential feeding using diets varying in energy and crude protein reduced the prevalence of birds with GS ≥3 from 61.3% to 42.0% without impairing growth performance (Leterrier *et al.*, 2008). A low energy, high protein diet and a high energy, low protein diet were rotated every 48 h from d 8 to d 28 or up to no fewer than 8 d before slaughter. The birds were then given a standard finishing diet from d 29 until the last day to compensate for reduced growth. The diet was designed for a production cycle of 38 d, which is 3–5 d longer than the average in Sweden (i.e. 32–35 d).

A fast growth rate increases the birds' susceptibility to lameness (Kestin *et al.*, 2001; Butterworth and Weeks, 2010). Feeding whole wheat to broiler chickens as part of their diet usually slows down digestion, thereby reducing growth rate, and for every percentage increase in dietary wheat (from 0 to 30%), there was a 0.017% improvement in flock GS during the third week of life (Knowles *et al.*, 2008).

Based on the earlier reports, 6 different management practices were selected for further analysis: (1) an increased daily period of darkness (8 h/d), (2) a decreased stocking density (27 kg/m^2), (3) meal feeding (2–4 times per day), (4) restricted feeding, (5) sequential feeding and (6) feeding whole wheat (on average 30% of feed during the production period).

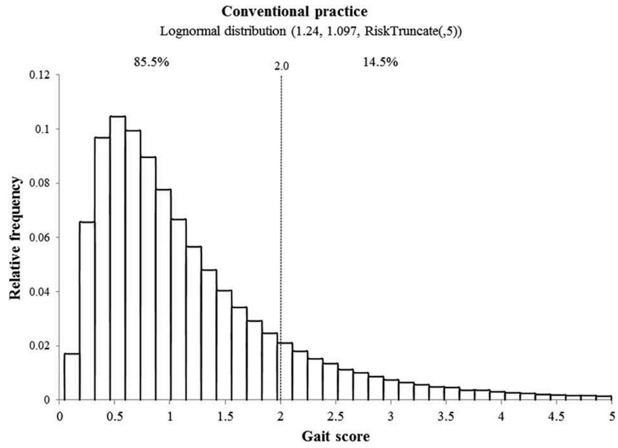

Figure 2. Relative frequency distribution of gait scores in the conventional situation (estimates based on Sanotra *et al.*, 2003).

Technical inputs

Data on the prevalence of lame birds (percentage of flock with a GS ≥3) and impact on production parameters were collected from the literature. The average prevalence of lame birds in the Swedish conventional system is 14.1% according to most recent reports (Sanotra *et al.*, 2003). Prevalence data for alternative practices are scarce. Most studies focused on the improvement in average flock GS achieved by using alternative practices rather than on explicit change in the proportions of broilers in the different gait categories. Hence, the following procedure was used to estimate the prevalence of lame birds in all alternative practices, except sequential feeding for which prevalence data were available.

(1) A continuous *lognormal* distribution was defined based on the parameters estimated from the discrete prevalence data with respect to the conventional practice described by Sanotra *et al.* (2003). Figure 2 shows a prevalence of lame birds (GS ≥3) in conventional practice of 14.5%, which roughly corresponds to the 14.1% reported by Sanotra *et al.* (2003). As a consequence of using a continuous rather than discrete distribution, the reference line indicating the relative frequency of birds with GS ≥3 is at 2 in Figure 2 (because a GS >2 fall in the category of GS ≥3). Note that the available data on prevalence were not suitable to estimate a discrete distribution for the different production practices as it would have required to estimate the frequency of broilers within the 6 different GS categories. Hence, the discrete distribution was transformed into a continuous one to be able to estimate the prevalence of lameness for the different production practices. That transformation resulted in the fact that Figure 2 suggests subscores, although in practice no subscores for GS are given.

(2) The improvement in average flock GS in the 5 alternative practices was established from the literature. The mean of the earlier defined lognormal distribution for conventional practice was adjusted with the improvement in the given practice while the standard deviation was held constant. In turn, for each practice, a lognormal distribution was defined with the adjusted mean and standard deviation (Table 1). On the basis of the established distributions, the prevalence of lame birds was estimated for each practice.

Table 2 presents the data on production parameters in healthy and lame broilers.

Economic inputs

Table 3 lists the main economic inputs, such as prices, variable and fixed costs included in the model (Agriwise, 2014). All calculations were made for a farm with a capacity of 80 000 chickens per cycle and it was assumed that one full-time labour equivalent (FTE) is available at the farm and can care for the 80 000 birds (Agriwise, 2014). Labour costs associated with 1 FTE were considered as fixed costs. Note that for most management practices no distinction was made in variable costs per chicken. In the case of feeding whole wheat, the price of feed (i.e. 3.46 SEK/kg) was lower than the price of conventional compound feed (i.e. 4.08 SEK/kg) because of the different feed composition. With regard to sequential feeding, no change in feed price was assumed compared to conventional practice.

Sensitivity analysis

Due to scarcity of data on the prevalence of lameness and its effect on production parameters in various management practices, uncertainty about input parameters influences the final model results. Sensitivity analysis was used to evaluate the

Table 1. Parameters of defined distribution to estimate prevalence of lame birds per production practices.

Practice	Lognormal distribution Mean	SD	Upper truncation limit	Estimated prevalence of birds with a gait score ≥3 (%)
Conventional	1.24[a]	1.09[a]	5	14.1[a]
Increased daily period of darkness	1.04[b]	1.09[a]	5	10.7
Decreased stocking density	1.07[c]	1.09[a]	5	11.2
Meal feeding	1.09[d]	1.09[a]	5	11.5
Restricted feeding	1.14[e]	1.09[a]	5	12.5
Sequential feeding	–	–	–	9.66[f]
Feeding whole wheat	0.99[g]	1.09[a]	5	9.8

[a]Prevalence of GS ≥3 is 14.1% in Ross 208 chickens (Sanotra *et al*., 2003).
[b]An improvement of 16% in GS is assumed compared to the conventional practice (Knowles *et al*., 2008).
[c]An improvement of 13.6% in GS is assumed compared to the conventional practice (Sørensen *et al*., 2000).
[d]An improvement of 12.3% in GS is assumed when changing from feeding *ad libitum* to meal feeding (Su *et al*., 1999).
[e]An improvement of 8% in GS is assumed compared to the conventional practice (Su *et al*., 1999).
[f]An improvement of 31.5% is assumed in the prevalence of birds with a GS ≥3 (Leterrier *et al*., 2008).
[g]An improvement of 0.51% in GS by increasing dietary feed with 30% (Knowles *et al*., 2008).

Table 2. Estimated impact of lameness (lame = gait score ≥3) in each of the alternative practices applied to the broiler farm.

Production system and practices	Daily weight gain (g/d)	Feed conversion rate (g feed/g gain)	Weight at delivery (g)	Mortality (% flock)	Condemnation (% flock)
Conventional production					
Healthy	49.29[a]	1.70[b]	1,725[b]	2[b]	1.5[b]
Lame (gait score ≥3)	39.29[c,d]	1.73[e]	1,375[f]	2.9[g]	1.8[g]
Practices to reduce lameness					
1. Increased daily period of darkness (8 h/d)					
Healthy	48.30[a]	1.67[h]	1,691[h]	2[b]	1.5[b]
Lame	38.30[c,d]	1.70[e]	1,341[f]	2.9[g]	1.8[g]
2. Decreased stocking density (27 kg/m^2)					
Healthy	49.88[a]	1.70[a]	1,746[i]	2[b]	1.5[b]
Lame	39.88[c,d]	1.73[e]	1,396[f]	2.9[g]	1.8[g]
3. Meal feeding (2–4 times per day)					
Healthy	46.82[a]	1.62[j]	1,639[j]	2[b]	1.5[b]
Lame	36.82[c,d]	1.65[e]	1,289[f]	2.9[g]	1.8[g]
4. Restricted feeding					
Healthy	46.82[a]	1.68[k]	1,639[k]	2[b]	1.5[b]
Lame	36.82[c,d]	1.71[e]	1,289[f]	2.9[g]	1.8[g]
5. Sequential feeding					
Healthy	49.29[l]	1.71[a,m]	1,873[b,m]	2[b]	1.5[b]
Lame	39.29[c,d]	1.74[e]	1,493[n]	2.9[g]	1.8[g]
6. Feeding whole wheat (on average 30% of feed)[o]					
Healthy	49.29[a]	1.80[o]	1,725[b,p]	2[b,p]	1.5[b]
Lame	39.29[c,d]	1.83[e]	1,375[f]	2.32[q]	1.8[g]

[a]Daily weight gain (g/d) = weight at delivery (g)/35 d.
[b]Agriwise (2014).
[c]The decrease in daily weight gain due to lameness in conventional system was assumed to be 10 g/d (Gocsik *et al*., 2014).
[d]Yalcin *et al*. (1998).
[e]The average feed conversion efficiency for chickens with GS4 and GS5 was 0.03 worse than that in the situation without leg problems (Su *et al*., 1999).
[f]Weight at delivery (g) = daily weight gain (g/d) × 35 d.
[g]Based on Verma (2007), Hall (2001) and Sullivan (1994) an increase of 0.9% in mortality was assumed due to lameness.
[h]Feed conversion was assumed to be improved by 1.7% applying lighting regimen of 16L:8D instead of 20L:4D Classen (2004).
[i]Sørensen *et al*. (2000).
[j]An improvement of 5% in feed conversion and a decrease of 5% in final body weight were assumed compared to the conventional situation (Su *et al*., 1999).
[k]Feed conversion was assumed to decrease by 1% and the final body weight was assumed to decrease by 5% compared to the conventional situation (Su *et al*., 1999).
[l]Daily weight gain = weight at delivery (g)/38 d.
[m]Feed conversion rate was assumed to be 1.71 for a production period of 38 d (Leterrier *et al*., 2008). Final body weight was recalculated for a production period of 38 d, i.e. 49.29 g/d × 38 d = 1873.02.
[n]Weight at delivery = daily weight gain (g/d) × 38 d.
[o]The proportion of whole wheat in the diet was assumed as, on average, 30% during the production period (Bennett *et al*., 1995, 2002; Knowles *et al*., 2008).
[p]An increase of 6% in feed conversion rate, as an effect of feeding whole wheat, was assumed. In mortality, no significant differences due to feeding whole wheat were observed (Bennett *et al*., 1995).
[q]A 20% lower mortality rate was estimated, i.e. 2.32%, compared to the mortality when lameness was present in conventional system (Bennett *et al*., 2002).

robustness of the results to the changes in input parameters. Thus, input parameters, such as prevalence of lameness and the daily weight gain, feed conversion rate, mortality and condemnation rate were varied systematically one at a time. Prevalence of lameness was changed by ±10%. By default the daily weight gain of lame birds was assumed to be 10 g/d lower than that of healthy ones. In the sensitivity analysis, the decrease of 10 g/d in daily weight gain was changed by ±5%.

Table 3. Economic inputs (Agriwise, 2014).

Variable	Unit	Value
Prices		
Feed price compound (65%)	SEK/kg	4.08
Feed price own production (35%)	SEK/kg	1.54
Wheat price	SEK/kg	2.00[a]
Price of 1-d-old chick	SEK/chick	3.61
Producer price of broiler chicken	SEK/kg	9.24
Variable costs		
Electricity	SEK/chicken	0.184
Heating	SEK/chicken	0.519
Catching and loading	SEK/chicken	0.531
Litter (straw)	SEK/chicken	0.061
Cleaning	SEK/chicken	0.265
Carrion collecting service	SEK/chicken	0.136
Environmental fee	SEK/chicken	0.020
General costs and insurance	SEK/chicken	0.075
Other	SEK/chicken	0.122
Fixed costs		
Labour own	SEK/h	220
Depreciation	%	3.7
Maintenance	%	1.5
Interest working capital	%	7
Interest buildings	%	3.5
Capital		
Working capital	SEK/m^2/round	32
Buildings and equipment	SEK/m^2/round	400

[a]Applicable in case of the calculations regarding the practice of feeding whole wheat as part of the diet. Average wheat price based on year March 2013–March 2014, No. 1 Hard Red Winter, ordinary protein, FOB Gulf of Mexico.

The feed conversion ratio in lame birds was originally assumed to be 0.03 higher than that of healthy ones; this was changed by ±0.1. Compared to healthy chickens, an increase of 0.9% in mortality was, by default, assumed due to lameness (Sullivan 1994; Hall, 2001; Verma, 2007). This increased mortality was changed by ±0.1% resulting in an increase of 0.8% and 1% compared to the healthy situation. In the case of feeding whole wheat, a lower increase in mortality was assumed than with other diets; here, although the level of change was similar at ±0.1%, the resultant increase in mortality amounted to 0.22% and 0.42%. An increase of 0.3% in condemnation due to skeletal problems was originally assumed and in the sensitivity analysis this increase in lame birds was changed by ±0.1%.

When feeding whole wheat, its price is an important driver of the feed costs. To evaluate the effect of changing feed price on the economic performance of this particular practice, wheat price was changed by ±5%.

Farmers' perceptions of lameness and practices to control lameness

Questionnaire

A questionnaire (administered using *Qualtrics* online survey software, Qualtrics Inc., Provo, UT, USA) was sent to Swedish broiler farmers during August to November 2014 to explore their perceptions of problems associated with lameness and of the management practices intended to control it. The questionnaire was pretested with a broiler specialist to ensure the questions were clear and it was edited accordingly. The resulting questionnaire consisted of three distinct parts. The first part contained questions about the farmer and the characteristics of the farm. The second part included questions regarding the farmer's perception of the relevance and importance of lameness in his/her farm. Thus, as well as questions on the exact figures for prevalence of lameness, mortality and culling due to lameness, which are often difficult for farmers to estimate, they were also asked if they perceived lameness as a minor, moderate or major problem and how they rank lameness in the context of other health problems. Finally, the third part focused on the farmer's thoughts on particular management practices intended to control lameness. Here, they were asked to rank an array of remedial practices in terms of their effectiveness and to add any others that were missing from the predefined list but might also be effective. They were also asked if they believed that a particular management practice could be effective in controlling lameness, and whether it is being used at their farm or if it would be in the future. The farmers were also asked to give reasons for their answers. This combination of quantitative and qualitative questions enabled us to get insight into the farmer's mindset, which primarily refers to their opinions, attitudes and beliefs regarding lameness, and the underlying motivation for lameness control and management in the farm.

Sample

An invitation to participate in the study was sent out by one of the largest slaughterhouses in Sweden to about 60 associated broiler farmers (50% of the broiler farmer population) (Björk, 2012). In total, 21 farmers responded, from which 9 fully and 12 partially completed the questionnaire. Given the relatively small number of returned questionnaires, it is cautioned that our results may not be easily generalised to the whole Swedish broiler farmer population. Therefore, we simply regard the survey results as a source of information that provides a good basis for further investigation and identifies some common viewpoints among the respondents.

The demographic and socio-economic characteristics of the sample are given in Table 4. The mean age (±SD) of respondents was 52 years (±10.1). Most respondents were males who had an agriculture-oriented education. Fourteen respondents had more than 20 years of farming experience. The mean (±SD) farm size was 5231 m^2 (±3325) and the stocking density in most farms was 36 kg/m^2. Mean (±SD) duration of the growth period was 35 d (±1.2). The dark period averaged, 6 h/d, of which 4 h were uninterrupted.

Results

Normative economic analysis

Gross margin

The financial performance of the broiler farm improved as a result of some of the practices designed to reduce lameness (Table 5). More specifically, the gross margin (return minus variable costs) of all but one alternative practice (i.e. restricted feeding) was higher than that of conventional practice. The greatest improvements in gross margin were realised when the practices of feeding whole wheat, sequential feeding or meal feeding were applied. Indeed, when whole wheat was fed the gross margin more than tripled compared to the conventional practice, this reflects the fact that whole wheat is cheaper than regular compounded feed. Although, the feed conversion rate of chickens fed whole wheat is less efficient, this effect is outweighed by a lower prevalence of lameness, a lower mortality and the lower feed costs. The latter factor contributed the most to the improved economic performance, whereas reduced

Table 4. Demographic and socio-economic characteristics of the sample.

Variable	N	Mean	SD
Farmer characteristics			
Age	15	52	10.1
Sex	17		
Male	*13*		
Female	*4*		
Highest level of education completed	17		
Primary school	*1*		
Secondary school: Agriculture	*2*		
Secondary school: Other	*3*		
Vocational/occupational degree: Agriculture	*3*		
Vocational/occupational degree: Other	*2*		
University/college: Agriculture	*5*		
University/college: Other	*1*		
Experience in farming	17		
Less than 5 years	*0*		
5–10 years	*1*		
11–15 years	*2*		
16–20 years	*0*		
More than 20 years	*14*		
Farm characteristics			
Farm size (m^2)	16	5231	3325
Stocking density (kg/m^2)	11	36	0
Growth period (d)	15	35	1.2
Dark period per day (h)	15	6	0.9
Uninterrupted dark period per day (h)	15	4	0.8

lameness played a minor role. Improved gross margins found in the other practices can also be primarily attributed to lower feed cost. However, in the case of sequential feeding, the average growth period, i.e. 38 d is longer than that in conventional practice and this results in a higher live weight at delivery and thereby the lower cost of 1-d-old chicks per kilogram live weight.

Net return to management

In terms of net return to management (return minus variable costs minus fixed costs), practices such as feeding whole wheat, sequential feeding, meal feeding and longer dark period performed better than the conventional practice. These improvements reflect the decrease in variable costs in relation to the gross margin (though fixed costs were similar to those of conventional practice). In contrast, decreased stocking density and restricted feeding had lower net return to management than conventional practice. With decreased stocking density, fixed costs related to investments in buildings and equipment were higher per kilogram live weight, which is a direct consequence of keeping fewer chickens per square metre. With restricted feeding, the slower growth rate than in conventional practice resulted in a lower live weight at delivery and, hence poorer returns.

Sensitivity analysis

In case of the various management practices, an increase of 10% in prevalence of lameness resulted in a decrease of about 1% in net return to management per kilogram, whereas a 10% decrease was associated with a 1% increase (Table 6). A 5% higher decrease (compared to the originally estimated 10 g/d) in the daily weight gain of lame birds resulted in a lower net return in all management systems (ranging from −1.70% to −2.40%) with the greatest decrease occurring when whole wheat was fed (−2.40%). In contrast, a 5% decrease in the daily weight gain of lame birds resulted in an increase in net return to management of 1.65–2.36% in the various management systems. When the increase in feed conversion rate of lame birds compared to healthy ones was reduced or increased by 0.1, the net return to management respectively increased or decreased by 0.2–0.3% in the various systems. Changing the increase in mortality or the condemnation rate of lame birds compared to healthy ones by ±0.1% led to a change ranging from −0.1% to +0.1% in net return to management. The sequence of management practices, from highest to lowest net return, was not sensitive to change in any of the input variables. More specifically, feeding whole wheat resulted in the highest net return to management. The sequential feeding, meal feeding and

Table 5. Return, production costs, gross margin and net return to management for different lameness-reducing practices (values in SEK per kg delivered broiler).

	Conventional	Longer dark period	Decreased stocking density	Meal feeding	Restricted feeding	Sequential feeding	Feeding whole wheat
Return	9.24	9.24	9.24	9.24	9.24	9.24	9.24
Variable costs	9.01	8.96	8.94	8.90	9.12	8.74	8.56
1-d-old chick	2.17	2.20	2.13	2.27	2.28	1.97	2.14
Feed	5.44	5.34	5.44	5.16	5.38	5.47	5.03
Electricity	0.11	0.11	0.11	0.12	0.12	0.10	0.11
Heating	0.31	0.32	0.31	0.33	0.33	0.28	0.31
Catching and loading	0.32	0.32	0.31	0.33	0.34	0.29	0.32
Litter (straw)	0.04	0.04	0.04	0.04	0.04	0.03	0.04
Cleaning	0.16	0.16	0.16	0.17	0.17	0.14	0.16
Carrion collecting service	0.08	0.08	0.08	0.09	0.09	0.07	0.08
Environmental fee	0.01	0.01	0.01	0.01	0.01	0.01	0.01
General costs and insurance	0.05	0.05	0.04	0.05	0.05	0.04	0.04
Other	0.07	0.07	0.07	0.08	0.08	0.07	0.07
Mortality	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Condemnations	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Fixed costs	1.72	1.73	2.07	1.76	1.77	1.78	1.71
Labour own	0.50	0.51	0.49	0.54	0.54	0.49	0.50
Depreciation	0.49	0.49	0.63	0.49	0.49	0.52	0.48
Maintenance	0.20	0.20	0.26	0.20	0.20	0.21	0.20
Interest buildings	0.46	0.46	0.60	0.46	0.47	0.49	0.46
Interest working capital	0.07	0.07	0.10	0.07	0.07	0.08	0.07
Total production costs	10.74	10.68	11.02	10.66	10.89	10.52	10.27
Gross margin	0.23	0.28	0.30	0.34	0.12	0.50	0.68
Net return to management	−1.50	−1.44	−1.78	−1.42	−1.65	−1.28	−1.03

Table 6. Sensitivity analysis (% change in net return to management).

Change in variable	Conventional	Longer dark period	Decreased stocking density	Meal feeding	Restricted feeding	Sequential feeding	Feeding whole wheat
Prevalence of lameness							
−10%	1.29%	1.05%	0.89%	1.22%	1.14%	0.99%	1.25%
+10%	−1.29%	−1.05%	−0.89%	−1.22%	−1.14%	−0.99%	−1.25%
Decrease in daily weight gain due to lameness							
−5%	1.18%	1.26%	1.18%	1.36%	1.17%	1.44%	1.69%
+5%	−1.21%	−1.29%	−1.21%	−1.40%	−1.20%	−1.48%	−1.74%
Increase in feed conversion rate due to lameness							
−0.01	0.3%	0.3%	0.2%	0.1%	0.3%	0.2%	0.3%
+0.01	−0.3%	−0.2%	−0.2%	−0.4%	−0.2%	−0.2%	−0.2%
Increase in mortality due to lameness							
−0.1%	0.1%	0.1%	0.1%	−0.1%	0.1%	0.1%	0.1%
+0.1%	−0.1%	0.0%	−0.1%	−0.2%	0.0%	−0.1%	0.0%
Increase in condemnation due to lameness							
−0.1%	0.1%	0.1%	0.1%	0.0%	0.2%	0.1%	0.2%
+0.1%	−0.1%	−0.1%	−0.1%	−0.2%	0.0%	−0.1%	−0.1%
Wheat price							
−5%	0%	0%	0%	0%	0%	0%	+3%
+5%	0%	0%	0%	0%	0%	0%	−3%

longer dark period practices also had a higher net return to management than did conventional practice. Changes of ±5% in wheat price resulted in a change of ±3% in net return to management.

Farmers’ perceptions of lameness and practices to control lameness

Lameness as a health concern

Thirteen respondents estimated the prevalence of lameness on the last day of production to be lower than the average of 14.1% of Ross 308 chickens and 26.1% of Cobb 500 chickens in Sweden reported by Sanotra *et al.* (2003) (Table 7). Four respondents regarded lameness as either a minor (*N* = 1) or a moderate problem (*N* = 3) in their farm, whereas the other 9 did not regard it as a problem.

Ascites (3), cardiac arrest (2), subcutaneous inflammations (2), small and underdeveloped animals, high mortality and heat stroke were named by 6 respondents as the greatest health problems. Six respondents identified foot pad dermatitis (4) and leg problems (3) as the most frequent health problems associated with lameness.

Adverse consequences of lameness

Culling and impaired growth rate were named as the most frequent adverse consequences of lameness (Table 8).

Table 7. Respondents’ perception of lameness in their farm.

Perception	*N*	*N*%
Prevalence of lameness on the last day of the production round	13	
Lower than 20%	*13*	*100*
Equal to 20%	*0*	*0*
Higher than 20%	*0*	*0*
Prevalence of lameness if different than 20%	5	
Less than 1%	*1*	
5%	*1*	
5–10%	*2*	
10%	*1*	
Lameness is considered as a problem in your farm	13	
Yes, I consider lameness as a problem	*4*	*31*
No, I do not consider lameness as a problem	*9*	*69*
The extent lameness is a problem in your farm	4	
A minor problem	*1*	*25*
A moderate problem	*3*	*75*
A large problem	*0*	*0*

Table 8. Indicated adverse consequences of lameness (*N* = 10).

About 50% of culling is due to leg problems, it happens early in the rearing period (d 7–20).
Animal suffering, burns (breast-, hock,- foot pad-) due to close contact with the manure.
High culling rate.
It is always a pity to cull healthy animals that for some reason have leg problems.
Low growth rate.
Negative effect on economic performance due to high number of culled animals and lower growth rate.
I have to cull birds that are not sick, but have leg problems.
The chicken is not feeling well and has to be culled.
The animals do not grow as they should.
Chickens need to be culled.

Eleven respondents further indicated that, on average, 0.1–0.7% of the flock needs to be culled due to lameness (mean = 0.48 ± 0.58%). Mean condemnation due to breast blisters, hock burns, foot pad lesions and fractures was 0.37 ± 0.40% of the flock; these issues are generally associated with lameness.

Management practices to control lameness

Respondents generally felt that the suggested practices could not effectively control lameness and some of their remarks are shown in Table 9. More specifically, none of them regarded the use of an 8-h dark period per day or sequential feeding as effective remedial strategies. A main concern about increasing the dark period was that chickens would become inactive and therefore would not eat; it was also expected to cause distress when lights were switched back on. Respondents were unfamiliar with sequential feeding and therefore failed to recognise its potential added value. Some practices, e.g. feeding whole wheat and meal feeding 2–4 times per day were more familiar and had already been applied by some respondents. Results also illustrate the fact that lameness is a complex problem and changing a single management factor may not be sufficient to reduce lameness. For example, respondents believed that changing stocking density would hardly affect lameness because they regarded genetic background and nutrition as more important factors.

Table 9. Perception of management practices to control lameness.

Management practice *Do you agree that … can be effective in controlling lameness?*	N		
	Total	*"Do not agree"*	*"Agree"*
… an increased dark period of 8 h/d …	9	9	0
… a decreased stocking density of 16 birds/m^2 …	8	7	1
… a meal feeding 2–4 times per day (the same quantity as *ad libitum*) …	8	6	2
… restricted feeding (restriction starts at age of 9 d lasting for 5 d) …	8	6	2
… sequential feeding (48-h cycles) …	8	8	0
… feeding whole wheat (30% of feed) …	8	4	4

Discussion

The main objectives of the present study were to explore the potential economic impact of implementing various alternative practices to reduce lameness in Swedish broiler farms, and to identify farmers' possible perceptions of their potential value in the Swedish context.

Results suggest that the application of certain alternative practices can provide better economic performance than conventional practice. Hence, within the Swedish context there seems to be potential to reduce lameness and to consequently improve animal welfare and economic performance. The alternative practices which realised the greatest improvements in gross margin and net return to management in the model were (in decreasing order) feeding whole wheat, sequential feeding and meal feeding. Improved economic performance when feeding whole wheat and meal feeding can mainly be attributed to decreased feed costs which respectively reflect a lower feed price and a more efficient feed conversion rate. In the case of sequential feeding, the decreased cost of d-old chicks (per kilogram delivered broiler) contributed most to the improved economic performance. The complex effect of changing feed composition on technical and economic performance is illustrated well in the case of feeding whole wheat. Feeding whole wheat resulted in a less efficient feed conversion rate, but a reduced mortality in lame chickens compared to the conventional practice. The negative effect of the practice on feed conversion rate was, however, outweighed by the effect of a low feed price (wheat is cheaper than compounded feed), which led to reduced feed costs. Moreover, the lower mortality rate reduced production costs per delivered broiler. It is suggested that farmers can substantially profit from the inclusion of whole wheat in their feeding programmes, but it must be realised that the price of wheat has a pivotal role in determining the level of potential profit. Reduced lameness actually contributed less to the improved economic performance.

Apparently, farmers did not perceive the win-win situation of the remedial practices in terms of economic performance and animal welfare despite the fact that their implementation could be of major importance in the broiler sector where profit margins are very small. There may be various reasons for this oversight. First, for example, our results suggest that farmers may not see lameness as a big problem so any improvements achieved by alternative practices might also be perceived as low. More specifically, 9 of the 13 farmers questioned did not consider lameness as a problem at their farm. Farmers' estimates of the prevalence of lameness at their farms ranged from less than 1% to 10%, which is lower than the 14.1% (for Ross 308 chickens) and 26.1% (for Cobb 500 chickens) reported by Sanotra *et al.* (2003). Of course, lameness is likely to have become less common since 2003 because improved leg health has been incorporated in the breeding goals (Dawkins and Layton, 2012). However, broiler farmers often fail to detect lameness in their farm (Butterworth and Haslam, 2009) or are less keen to detect it when there are no obvious, clinical signs of the problem. A recent Belgian study (Tuyttens *et al.*, 2014) also indicated that there might be some denial by broiler farmers of welfare problems in their birds. Similarly, dairy cow farmers were found to highly underestimate lameness in their herds (Sárová *et al.*, 2011). Second, the farmers may have more overwhelming problems than lameness, such as negative net returns due to other factors. There is also a possibility of respondent bias, i.e. farmers with less lameness were also more willing to answer the questionnaire, which may account for the difference between our findings and other reports. Third, farmers may primarily focus on the potential negative production effects of an alternative practice, e.g. a higher feed conversion rate, and fail to see the accompanying economic advantages, e.g. lower feed cost when feeding whole wheat. Encouragingly though, some farmers seem to be recognising the win-win potential of alternative practices because some of our respondents were already using the whole wheat and meal feeding strategies.

The present economic model assumed that chickens were kept for a fixed production period. As a consequence, lame broilers (if not culled) were delivered with a lower weight since lameness usually leads to an impaired daily growth (Yalcin *et al.*, 1998). This assumption results in a lower revenue for lame broilers than for healthy ones. Another way to deal with the differences in growth rate between healthy and lame broilers would be to assume that lame birds are kept for longer to reach the same weight as healthy ones. This assumption, however, was not included in the analysis because lameness can become more severe with increasing age (Butterworth and Haslam, 2009) and can negatively impact productivity and financial performance. Detailed input data to model these effects, however, was not available. Keeping lame broilers for longer to increase their final weight is not feasible or desirable for at least three reasons: (1) the flock would have to be delivered in two batches rather than the normal practice of one batch; (2) more importantly, keeping and selling severely lame broilers raises ethical questions; and (3) transportation of lame birds is not allowed in Sweden.

A normative modelling approach was used to address the economic impact of lameness-reducing management practices. This meant that input data is often not readily available and certain assumptions and estimations had to be made to carry out the analysis. Therefore, we must reflect on the quality of the input data and the potential uncertainties in modelling outcomes. First, input data regarding the production effect of various practices to reduce lameness were usually estimated on the basis of small-scale experiments reported in the scientific literature because there is a lack of commercially based evidence. This might also explain why farmers failed to recognise the estimated impact of the suggested management practices – farmers may have the experience of how the practices may work for them in their commercial settings, or at least they can imagine what the practices may lead to for them. Second, various sources were used to estimate the impact of a particular management practice on production performance and prevalence of lameness. The starting points and settings differed between some of the studies that we based our model on. Nevertheless, for the economic analysis, it was necessary to establish exact parameters by combining the information from these various studies despite their different starting points. For example, in the case of feeding whole wheat, the proportion of whole wheat in the diet varied during the production period in the different studies, but to establish a common ground in the present study it was assumed that the average proportion of whole wheat in the diet is 30% during the production period. Of course, this assumption influences the estimated feed price and hence the resultant feed costs and net returns. Therefore, the extent of economic improvement associated with the alternative feeding practice should be interpreted with care. A sensitivity analysis, which is often used to examine the robustness of results to changes in a certain input parameter when other variables are held constant (Pannell, 1997), was carried out here with regard to input parameters such as prevalence of lameness and performance of lame animals. The outcomes suggest that the model results are robust in a sense that the sequence of management practices, from the highest to the lowest net return to management, remained unchanged when any of the input variables are altered. Thus, the three best performing management practices were feeding whole wheat, sequential feeding and meal feeding. A limitation of such a sensitivity analysis is, however, that interactions between production parameters cannot be taken into account. Hence, the primary task required to increase the accuracy of economic calculations is to improve the accuracy of input parameters. In the case of feeding whole wheat, further research should primarily focus on the relations between the proportion of whole wheat in the diet and feed conversion ratio as well as other production parameters.

Caution must be taken when generalising the results of the present small sample size to a larger population, e.g. the whole Swedish broiler farmer population (Flyvbjerg, 2006). However, the farmers' responses were consistent and offer a wealth of information on their considerations regarding lameness and alternative management practices. Clearly, further research on a larger commercial scale is merited.

In conclusion, the present study indicates that some alternative practices (especially feeding whole wheat, sequential feeding and meal feeding) may not only improve broiler welfare by reducing the prevalence of lameness but may also enhance economic performance. Thus, if these practices are applied in specific situations, a win-win effect in terms of welfare and profitability could be generated. Although reduced lameness contributes to an improved economic performance, the effects of lower feed prices (e.g. when feeding whole wheat) and more efficient feed conversion (e.g. when using meal feeding) on improved economic performance are generally more influential. However, the farmers who participated in the survey did not seem to recognise the potential combined positive effects of changing feed or feeding practices on both broiler welfare and farm economics. There is a clear and pressing need for a wider and more transparent dissemination of the present findings.

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