Animal Welfare 2012, 21(S1): 57-64
doi: 10.7120/096272812X13345905673683
ISSN 0962-7286

Interactions between profit and welfare on extensive sheep farms

AW Stott*[†], B Vosough Ahmadi[‡], CM Dwyer[§], B Kupiec[‡], C Morgan-Davies[†], CE Milne[†], S Ringrose[‡], P Goddard[#], K Phillips[¥] and A Waterhouse[†]

[†] Future Farming Systems Research Group, Scottish Agricultural College, King's Buildings, West Mains Road, Edinburgh EH9 3JG, UK
[‡] Land Economy and Environment Research Group, Scottish Agricultural College, King's Buildings, West Mains Road, Edinburgh EH9 3JG, UK
[§] Animal Behaviour and Welfare, Scottish Agricultural College, King's Buildings, West Mains Road, Edinburgh EH9 3JG, UK
[#] James Hutton Institute, Craigiebuckler, Aberdeen AB15 8QH, UK
[¥] ADAS, Animal Health and Welfare, Woodthorne, Wergs Road, Wolverhampton WV6 8TQ, UK
* Contact for correspondence and requests for reprints: alistair.stott@sac.ac.uk

Abstract

Extensive sheep farming systems make an important contribution to socio-economic well-being and the 'ecosystem services' that flow from large areas of the UK and elsewhere. They are therefore subject to much policy intervention. However, the animal welfare implications of such interventions and their economic drivers are rarely considered. Under Defra project AW1024 (a further study to assess the interaction between economics, husbandry and animal welfare in large, extensively managed sheep flocks) we therefore assessed the interaction between profit and animal welfare on extensive sheep farms. A detailed inventory of resources, resource deployment and technical performance was constructed for 20 commercial extensive sheep farms in Great Britain (equal numbers from the Scottish Highlands, Cumbria, Peak District and mid-Wales). Farms were drawn from focus groups in these regions where participative research with farmers added further information. These data were summarised and presented to a panel of 12 experts for welfare assessment. We used two welfare assessment methods one drawn from animal welfare science ('needs' based) the other from management science (Service Quality Modelling). The methods gave complementary results. The inventory data were also used to build a linear programme (LP) model of sheep, labour and feed-resource management month-by-month on each farm throughout the farming year. By setting the LP to adjust farm management to maximise gross margin under each farm's circumstances we had an objective way to explore resource allocations, their constraints and welfare implications under alternative policy response scenarios. Regression of indicators of extensification (labour per ewe, in-bye land per ewe, hill area per ewe and lambs weaned per ewe) on overall welfare score explained 0.66 of variation with labour and lambs weaned per ewe both positive coefficients. Neither gross margin nor flock size were correlated with welfare score. Gross margin was also uncorrelated with these indicators of extensification with the exception of labour/ewe, which was negatively correlated with flock size and hence with gross margin. These results suggest animal welfare is best served by reduced extensification while greater profits are found in flock expansion with reduced labour input per ewe and no increase in other inputs or in productivity. Such potential conflicts should be considered as policy adjusts to meet the requirements for sustainable land use in the hills and uplands.

Keywords: *animal welfare, economics, linear programming, profit, service quality modelling, sheep*

Introduction

The global population is expected to grow rapidly over the following 40 years. This is likely to be accompanied by increased *per capita* consumption as affluence increases. Increasing strain will therefore be placed on the food system, potentially exacerbated by climate change (Godfray *et al* 2010). This has led to increasing emphasis on food security, agricultural productivity and its associated environmental impacts (Foresight 2011). However, in Great Britain and many other areas of the world, much agricultural land is in rough grazing devoted to extensive sheep production with few alternative uses. These systems are sustained only by heavy reliance upon agricultural subsidy and yet make a small and reducing contribution to rural employment and economic development (Matthews *et al* 2006). The disproportionate contribution of ruminant agriculture to greenhouse gas emissions and hence to climate change (Gill *et al* 2010) coupled with low productivity from extensive sheep systems adds to pressure for change in subsidy support to this sector and hence to the nature and extent of farming practice. However, these farming practices are an integral part of the wider ecology of the uplands, which deliver/maintain a wide range of ecosystem 'services'; including biodiversity, landscape features, climate and flood regulation, water supplies etc upon which a wide range of human livelihoods depend (Reed *et al* 2009).

These dilemmas have led to research on the relationship between policy, farming activity in the hills and uplands and its impact upon ecosystems services (eg Angus *et al* 2009; Acs *et al* 2010). Meanwhile, sheep numbers in some important extensive sheep farming regions of Scotland have been declining rapidly in recent years (SAC 2008a) in response to the decoupling of subsidy from production in the EU, which was implemented in 2005. However, little research has been done on the impacts that such change may be having on animal welfare. The objective of this paper is therefore to examine the relationship between profit, farm management and animal welfare on a sample of extensive sheep farms in Great Britain in order to improve understanding of the potential impacts of changing policy and farming practice on animal welfare.

Our objective required a method of welfare assessment suited to extensive sheep farming systems. Unfortunately, little previous research has been done on animal welfare in such systems. This may be because such systems are considered to offer already high levels of animal welfare (Dwyer & Lawrence, 2008). However, although they offer more opportunities than in other systems for animals to exhibit their natural behaviours, the other 'freedoms' from hunger/thirst, discomfort, pain/injury/disease and fear/distress (FAWC 1994) may still be compromised. In the absence of alternatives, we have previously used adaptive conjoint analysis (Green & Srinivasan 1990) to measure the welfare of extensive sheep in terms of the husbandry practices employed (Stott *et al* 2005). However, we needed a wider, more flexible approach in this current case, based as far as possible on the animals' perspective. A secondary objective of this paper was, therefore, to develop and test a suitable method of welfare assessment.

The relationship between agricultural policy and land-use decisions has been examined previously using linear programming (LP) (eg Acs *et al* 2010). The technique finds the decision set that maximises an objective function (usually farm profit in this context) subject to a set of constraints that represent the farming system of interest. (For examples applied to farm animal welfare see Stott *et al* [2005] and Vosough Ahmadi *et al* [2011]). Previous work at the farm level on policy analysis concerned with land-use change in marginal areas has shown LP to be a robust technique in this context (Hanley *et al* 1998). However, the fixed generic assumptions generally used in such models, which may be sufficient to represent a typical farming system within a region, may be inadequate when applied to the individual farm situation as required here. A further secondary objective of this paper was therefore to develop an LP, based on individual farm data that was sufficient to estimate profit potential for comparison with welfare assessment.

Materials and methods

Farm data

Primary data were collected from twenty farms representing four mountain regions in the UK (Scottish Highlands, Cumbria, Peak District and mid-Wales). The data included a detailed farm inventory and qualitative profiles of farmers constructed using a laddering exercise (Rekom & Wierenga 2007) and in-depth interviews carried out separately on each farm. Farm and farmer-manager profiles describing the resources, managerial capabilities, attitudes, views and interests of farmers were provided to expert animal welfare assessors. Due to space restrictions, further details of all data collection and analysis are available from the corresponding author on request and will be published in more detail at a later date.

Welfare assessment

We adapted the EU-funded Welfare Quality® (FOOD.CT.2004.506508) project's Welfare Quality® criteria (Keeling & Veissier 2005) to suit extensive sheep farming systems. The ten welfare criteria assessed were: absence of prolonged hunger and thirst; physical comfort; absence of pain; normal social behaviour; human-animal relationship; absence of negative emotions; positive emotions; specific welfare knowledge/stockmanship; health-injuries and health-disease. To generate welfare assessment scores we devised a Qualitative Welfare Assessment (QWA) approach where the ability of a farm to meet the above criteria was assessed by experts using a Visual Analogue Scoring scale (ranging from 'provides worst possible welfare' at 0 cm on the scale, to 'provides best possible welfare' at 10.7 cm on the scale). To aid the use of this information for welfare assessment, each inventory was converted into a 'farm pen picture'. Twelve sheep welfare experts from different backgrounds (three consultants, four sheep farmers, three veterinary surgeons, two welfare experts) were instructed to provide a welfare score on each of the ten welfare criteria for each of the 20 farm pen pictures presented to them in a randomised order. Welfare score data were not normally distributed, therefore the differences between farms and between experts in average welfare score, and between scores given to different welfare criteria were analysed by Kruskal-Wallis non-parametric ANOVA. Association between welfare scores and particular farm traits were determined by Pearson's correlation.

A welfare assessment was carried out in parallel to QWA using the Service Quality Model (SQM) approach, (Parasuraman *et al* 1988). This is a well-tried methodology used in the service industry to facilitate assurance of good standards. However, we think this is the first application to animal welfare. The approach involves five quality dimensions: tangibles, reliability, assurance, responsiveness, and empathy (Parasuraman *et al* 1988). These qualities are measured in terms of the gap between expectations (the benchmark) and perceptions of the way the service has been performed in practice (Caruana *et al* 2000). In our adapted

https://doi.org/10.7120/096272812X13345905673683 Published online by Cambridge University Press

model, animal welfare is taken to be a function of the quality of service provided to an animal in the course of its life, and these five quality dimensions were modified to represent six specific factors impacting on animal welfare: 'nutrition' (quality and quantity of feed); 'health-care' (identification of animal condition, prevention and treatment); 'reliability' (timeliness and quality of actions); 'knowledge and experience' (of farmers and other employees dealing with animals); 'empathy' (individualised treatment of an animal); and 'human intervention' (actions related to production processes performed on an animal such as castration). Animal welfare assessment with SQM depends on the interpretation of the process outcome by experts able to gauge information on farm resources and management capabilities in the context of good animal welfare standards. We therefore asked our expert panel to score provision of welfare to sheep based on the farm information supplied to them by rating each of 37 requirements on a seven-point scale from 1 (not at all essential) to 7 (absolutely essential). They also scored a 'model' farm that would deliver optimum welfare to an animal. This model farm acted as the benchmark. These requirements were later related back to the six specific factors impacting on animal welfare listed above to form the basis of the SQM scores.

Farm LP model

We developed an LP for each for the 20 farms based on the inventory used for welfare assessment plus an additional survey to collect further details of management practices. The objective of the LP was to maximise sheep enterprise gross margin subject to land, labour and sheep performance constraints. The LP followed the sheep farming year in a series of monthly periods. In each month, grass feed energy supply from hill, pasture and in-bye land on the farm was calculated using the model of Armstrong *et al* (1997). This was matched with the ewe flock's demand for feed energy, given the average ewe's metabolisable energy requirements based on AFRC (1993). These, in turn, depended on the relevant performances and decisions recorded in the inventory for the 2007–2008 season, such as lambing date, twinning rate, weaning percent, breed of sheep, areas of different land types, fertiliser usage etc. Grass yields on land shut-off for conservation were accumulated in the LP as hay or silage and made available later as required. Where home-grown stocks were inadequate, hay (at £70 per tonne) and/or concentrates (at £250 per tonne) could be purchased as required. Variable costs of hill, pasture and conservation land were £0, £11 and £27 per hectare for hill, pasture and conservation land, respectively (SAC 2008b), excluding fertiliser costs calculated at the rate of £0.47 kg^{-1} depending on reported usage. Other variable costs (£10.58) were taken from SAC (2008b). Where farms sold surplus lambs finished rather than as store, an additional gross margin of £2.61 per lamb was added.

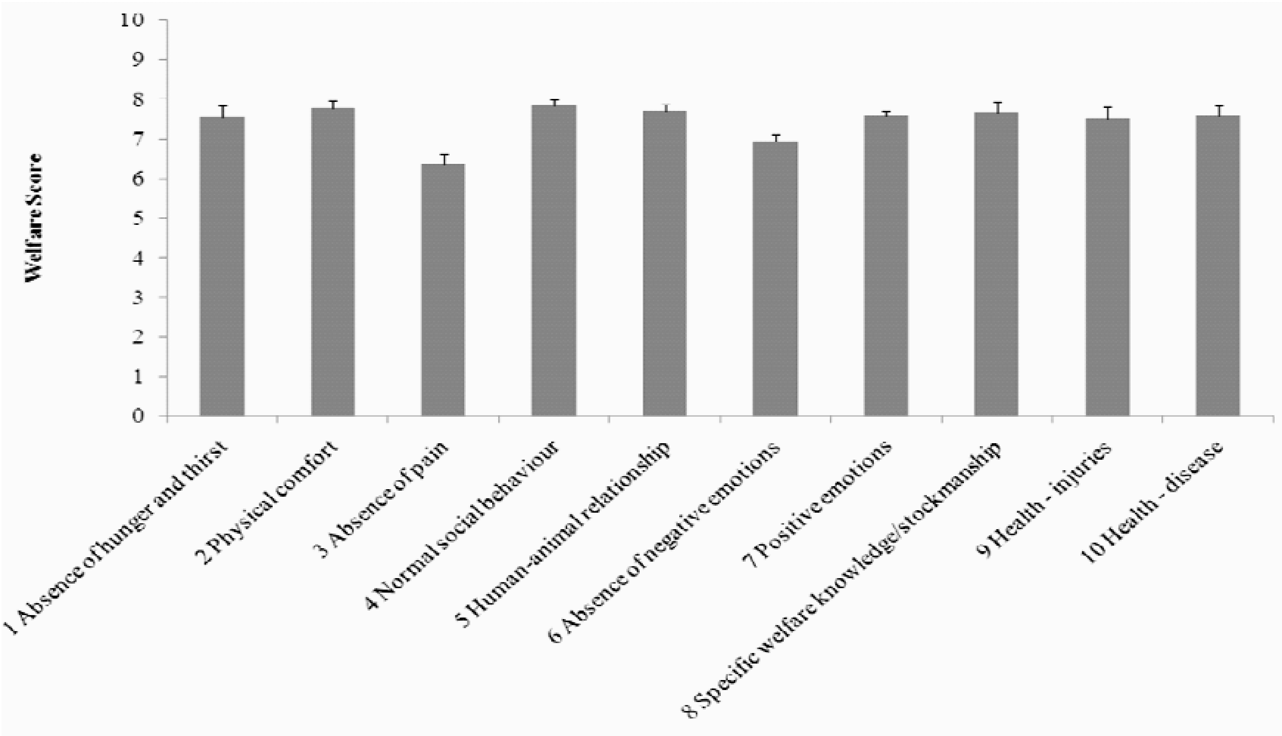
A labour profile detailing supply of labour to the flock each month (Stott *et al* 2009) was available from the inventory data and expressed as a set of constraints in the LP. The demand for labour per ewe was estimated based on the welfare assessment. It was hypothesised that QWA score was dependent on key attributes of the studied farms such as available land areas, available on-farm labour as well as productivity. To test this hypothesis, a multiple linear regression analysis was conducted with farm overall QWA as the response variable. The independent variables consisted of labour supplied in hours per ewe per year, in-bye land (better quality land close to the farmstead) per ewe (Ha), hill land per ewe (Ha) and ewe performance (lambs weaned per ewe). From the regression equation, 'fitted welfare scores' were determined for each farm. By setting the dependent variable (ie average qualitative welfare assessment score) in the regression equation to its maximum fitted value for all farms and solving for labour per ewe on every farm, the labour demand for each farm was estimated. Where labour demand exceeded supply, additional labour could be purchased. However, for the purposes of this paper, additional labour was assumed to be freely available. This allowed the LP to estimate the profit potential of each farm in a consistent way that reflected the land resources available, decisions applied to the land and flock and flock performance in each case. This could then be compared to the welfare assessment.

Results

The mean QWA scores for each welfare criteria are presented in Figure 1. Farms and experts differed significantly from one another in their scores (Farms: Kruskal Wallis, $H = 414.06$, df = 19, $P < 0.001$; Experts: $H = 353.53$, df = 11, $P < 0.001$). However, agreement between experts for individual farm scores was good (SD of mean scores ranged from 1.1 to 2.0 points). Although all criteria scored above the mid-point, on average; 'absence of pain' and 'absence of negative emotions' had significantly lower scores (Figure 1, $H = 125.97$, df = 9, $P < 0.001$) than other criteria. Experts assigned highest welfare scores for most criteria to farms with higher productivity (lambs weaned per breeding ewe) and those that were least extensive (housed at lambing, highest number of gathers, greatest amount of in-bye land to hill). By contrast, none of these factors were associated with score 4 'normal social behaviour' where high scores were related to the amount of extensive grazing land available ($P < 0.05$), and tended to be associated with a low inspection frequency ($P = 0.078$) and a high number of breeding ewes on the farm ($P = 0.073$). The average of 9 QWA scores excluding 4 was therefore taken as an overall measure of farm welfare for comparison with productivity (Figure 2) and profit. Regression of indicators of extensification (labour per ewe, in-bye land per ewe, hill land per ewe and lambs weaned per ewe) on overall welfare score explained 0.66 of variation with labour and lambs weaned per ewe both positive coefficients (1.2 [± 0.5] and 1.9 [± 0.6], respectively). (The intercept of the regression equation was 4.5 [± 0.6] and the other two coefficients in-bye land per ewe at 7.6 [± 4.9] and hill land per ewe at –0.04 [± 0.03]).

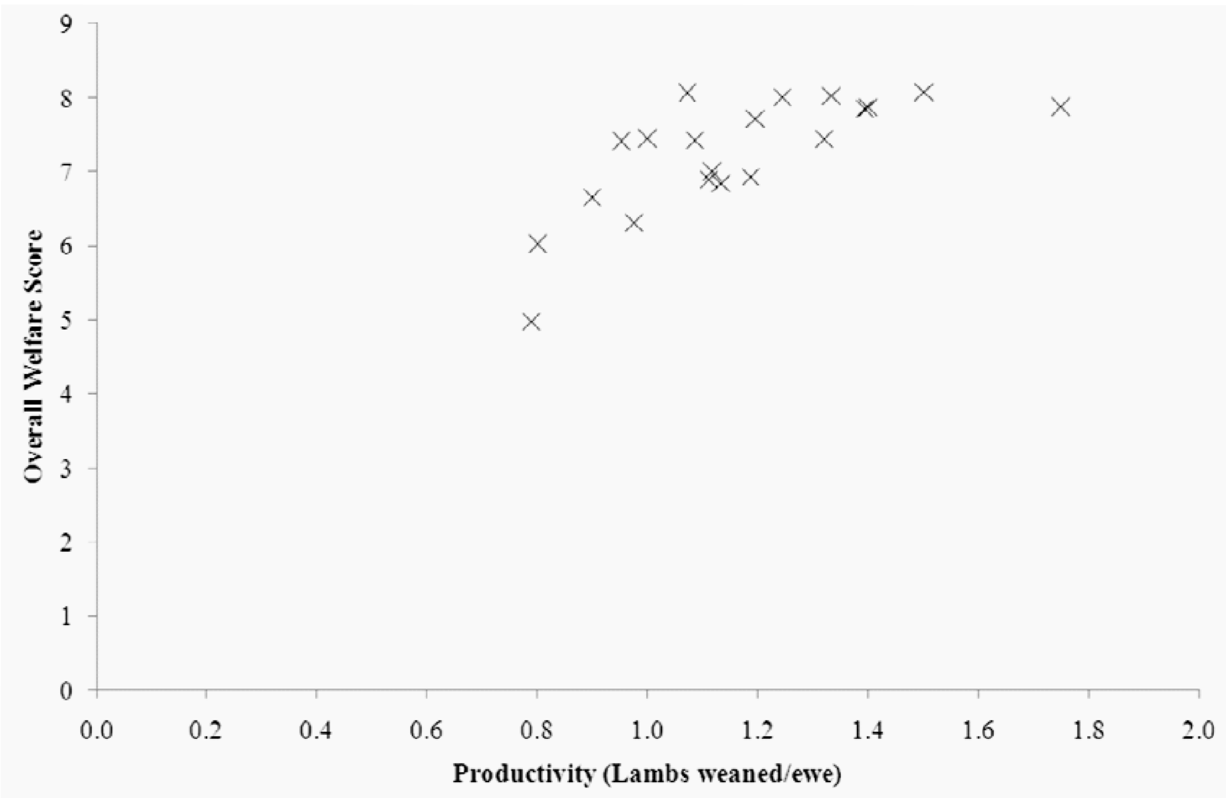
Results of the SQM method of welfare assessment across all 20 farms are shown in Table 1. The gap between assessment

Figure 1



Mean (± SEM) overall welfare scores on 20 extensive sheep farms.

Figure 2



Relationship between productivity and overall welfare score on 20 extensive sheep farms.

https://doi.org/10.7120/096272812X13345905673683 Published online by Cambridge University Press

Table 1 Summary of SQM average welfare scores for all 20 farms.

Factor/Dimension	Importance/Weight	Assessment	Benchmark	Gap
Nutrition	0.3	4.94	6.18	–1.24
Health	0.2	5.04	6.11	–1.07
Reliability	0.1	5.46	5.80	–0.34
Knowledge	0.2	5.27	6.08	–0.81
Empathy	0.1	5.33	5.85	–0.52
Intervention	0.1	4.62	6.10	–1.48
Overall	Weighted average	5.23	6.07	–0.83

Table 2 Ewe numbers and enterprise gross margins predicted by the LP with actual ewe numbers and resources available to every farm in the sample.

Farm number*	Ewe number		Gross margin (£ year)	Resources (Ha or Hours per month)			
	Actual	Predicted		Hill	Pasture	In-bye	Labour
1	2,222	1,230	8,337	1,900	125	40	237
2	645	480	7,619	373	9	11	596
3	530	248	4,398	280	0	14	394
4	350	350	3,666	623	41	4	230
5	1,150	1,150	13,349	1,300	194	9	245
6	720	720	7,913	168	30	15	254
7	2,000	988	5,077	1,400	77	0	614
8	850	850	12,835	470	168	32	203
9	900	792	7,181	550	34	4	267
10	1,600	1,600	21,283	627	135	6	292
11	1,600	1,600	39,748	30	284	8	473
12	578	578	4,029	18	92	8	234
13	752	752	10,053	160	40	34	139
14	420	420	3,192	104	39	8	234
15	600	600	12,411	10	50	17	233
16	660	660	8,908	592	27	8	200
17	200	200	2,342	5,694	28	0	250
18	271	59	243	576	5	0	32
19	500	500	11,393	4,031	128	62	198
20	425	425	7,210	1,600	40	0	400

* Farms 1–5 Peak District, 6–10 Cumbria, 11–15 Scotland, 16–20 mid-Wales.

and the benchmark assigned by the expert assessors indicates that performance was generally good (in-line with QWA scores) but with some room for improvement, especially in nutrition and human intervention. In the latter dimension, the gap for potentially painful tasks (castration, tail docking, foot care etc) was particularly wide at –2.38. This result mirrors the low score for absence of pain in the QWA analysis (Figure 1). Cluster analysis (not reported here) revealed most between-cluster differences were in the nutrition dimension with least variation in human intervention, suggesting that the negative impact of procedures carried out on the animals is a common feature (in this study, all farms castrated lambs, and all but one farm tail docked lambs).

Results of the LP model run are shown in Table 2. Six farms achieved a higher gross margin (shown) where flock size was lower than actual ewe numbers on the farm. This was caused by insufficient resources to support the flock, necessitating purchase of relatively expensive feeds to meet the energy requirements of the ewes. In some cases, these farms had access to off-farm grazings not included in the LP (but known to the welfare assessors). However, the correlation between welfare score for absence of hunger and thirst and the difference between predicted and actual ewe numbers was high (–0.72). Also, three out of four farms with the greatest shortfall in predicted ewe numbers occupied the three lowest positions in farms ranked by this welfare criterion.

The correlation between overall welfare score and predicted gross margin was positive but not significant. The correlation between actual flock size and overall welfare score was negative but not significantly so. However, the correlations between lambs weaned per ewe and labour per ewe with predicted gross margin were 0.6 and –0.4, respectively, and significant ($P < 0.01$ and $P = 0.05$, respectively).

Discussion

We have made an in-depth study of a small number of extensive sheep farms. These exhibited a wide range of farm situations (Table 2), welfare scores and production performances (Figure 2). Despite this, some important general trends emerged. In contrast to more intensive systems, where increased productivity may be at the expense of animal welfare (McInerney 2004), in our sample the opposite was true. However, overall welfare score was not strongly correlated with gross margin to deliver the 'win-win' opportunities that can sometimes be found to justify supply-side driven improvements in animal welfare (Lawrence & Stott 2009). Furthermore, labour input per ewe was associated positively with overall welfare score but negatively associated with gross margin. These antagonistic relationships with labour have been shown previously by Stott *et al* (2005) but based on specific husbandry activities rather than whole farm performance as measured here. The relationship between gross margin and labour input per ewe reflects the greater labour input per ewe and lower gross margins found on small farms. Such farms therefore have a dual incentive to expand in search of both higher gross margins and lower labour costs, leading to much greater profitability. These incentives are most likely to increase as direct financial support via agricultural policy decreases and policy emphasis shifts towards cross-compliance with environmental measures and diversification (Reed *et al* 2009). Our results suggest that reduced animal welfare may be an unintended consequence of such policy change in the extensive sheep sector. A key issue for animal welfare in this policy situation is by how much and in what ways may the negative effect of reduced labour input be offset by the positive effects of increased productivity as both may contribute to improved profits from sheep farming to replace potential reductions in agricultural subsidy?

Our two methods of welfare assessment have their roots in different disciplines but both highlighted key issues of nutrition and freedom from pain in extensive sheep farming systems. In both methods, expert assessors based their scores on an animals' perspective but no direct animal measures were taken. Welfare can be assessed by looking at resources, management or by animal-based criteria. It is generally accepted that animal-based measures are the preferred method of assessment. However, this is difficult to apply to extensively managed animals except in very specific conditions (eg Turner & Dwyer 2007) and there is a lack of well-validated welfare indicators for extensively managed sheep. In addition, the welfare of sheep in extensive systems is potentially influenced more by the management strategy of the farmer and the availability of resources (such as grass) than for animals in other systems. Therefore, whilst our welfare assessment methods need to be validated against animal-based methods, they do consider the impact of management on welfare, which is frequently not considered in detail. A potential advantage of our SQM approach in this context is that it sets out to measure gaps in service quality as provided by management in support of animal welfare rather than animal welfare *per se*.

One finding of this study is that a measure of productivity, number of lambs weaned per breeding ewe, was significantly positively correlated with overall welfare score. Although there are sound biological reasons why productivity may be impaired with poor welfare (for a review, see Dwyer & Bornett 2004), productivity as a measure of welfare is generally not regarded favourably as highly selected animals will still produce at high levels in conditions of poor welfare. However, this situation occurs in intensive management systems where animals receive considerable additional support. In extensive systems, as in this study, where productivity is already very low, production indicators may be useful indicators of welfare, particularly of poor welfare.

In this study, all QWA welfare criteria were considered as having equal weight in the development of the overall welfare score, with the exception of 'normal social behaviour' which was excluded. This was justified in this study since all nine included criteria showed the same relationship with other measures included in the model. However, whether these criteria are valued equally by the sheep is not known. In particular, the criterion of 'normal social behaviour' was associated with different environmental features, and when considered alone, a different ranking of farms for animal welfare. The SQM method did include a weighting factor (see Table 1) agreed by the welfare assessors. This highlighted the importance of the nutrition gap.

Our LP model has much in common with LP models used to predict the impact of policy change on farm decisions and hence on land use change (eg Acs *et al* 2010). However, we incorporate aspects of animal-based farm-level models (eg Conington *et al* 2004) and a model of vegetation growth under sheep grazing (Armstrong *et al* 1997). This allows us to predict technical coefficients for the LP that fit individual farm circumstances for each month of a typical farming year. The technical coefficients in an LP link resource supply (eg grass growth) with the farming activities that use the resources (eg ewes). (For further details of LP, see a specialist textbook such as Williams 2008). Our approach therefore ensures that input-output relationships that are usually explicit in a science-based model but often fixed in an LP are linked with the decision-making (optimum-resource allocation) focus of the LP. The LP therefore models the gross margin maximising farmers' resource-allocation decisions subject to the resource and performance limitations that apply to a particular farm situation. It therefore provides an objective benchmarking framework with which to assess the profit potential of each farm in our sample. Obviously there are simplifications in our LP that make the model more tractable and/or reflect the limitations of data available. For example, we limit food energy demand to that of the average ewe on the farm in terms of its weight, date of conception, lambing, weaning, number of lambs weaned etc. Three land types are considered as explained earlier, each with one grass species typical of that land type with, in addition, a proportion of heather on the hill land estimated by the farmer. Predicted grass growth was sensitive to height above sea level for hill and lower ground estimated by the farmer. This was therefore corroborated with reference to satellite maps available freely on the internet. However, the model performed well when validated against performance at SAC's Hill and Mountain Research Centre farm and published farm sector income statistics (SAC 2008b).

Conclusion

Our two methods of welfare assessment gave comparable and generally high scores for the extensive sheep farms in our sample. However, they identified animal nutrition and human interventions associated with pain as particular challenges. High overall welfare scores were associated with high productivity and high labour input per ewe but not with higher financial performance. This suggests that animal welfare could suffer as farms expand and lower costs in response to reform of agricultural subsidy on which these farms are heavily dependent. Intervention to improve productivity may help to address this potential problem.

Acknowledgements

The authors wish to thank the Department for Environment, Food and Rural Affairs (Defra) of the UK for funding this research under project AW1024. Ron Duncan, Nerys Davies and John Rockcliffe are gratefully acknowledged for farm and farmer data collection. We are also most grateful to the 12 expert welfare assessors, to the 20 farmers and their families who supplied the farm data and the approximately 80 other farmers who participated in the research on a regular basis. Dr Hans Erhard is particularly acknowledged for his contribution to the welfare assessment work.

References

Acs S, Hanley N, Dallimer M, Gaston KJ, Robertson P, Wilson P and Armsworth PR 2010 The effect of decoupling on marginal agricultural systems: implications for farm incomes, land use and upland ecology. *Land Use Policy 27*: 550-563. http://dx.doi.org/10.1016/j.landusepol.2009.07.009

AFRC 1993 Energy and Protein requirements of Ruminants. *An advisory manual prepared by the AFRC Technical Committee on Responses to Nutrients.* CAB International: Wallingford, UK

Angus A, Burgess PJ, Morris J and Lingard J 2009 Agriculture and land use: demand for and supply of agricultural commodities, characteristics of the farming and food industries, and implications for land use in the UK. *Land Use Policy 26*: S230-S242. http://dx.doi.org/10.1016/j.landusepol.2009.09.020

Armstrong HM, Gordon IJ, Grant SA, Hutchings NJ, Milne JA and Sibbald AR 1997 A model of the grazing of hill vegetation by sheep in the UK. I The prediction of vegetation biomass. *Journal of Applied Ecology 34*: 166-185. http://dx.doi.org/10.2307/2404857

Caruana A, Ewing MT and Ramaseshan B 2000 Assessment of the three-column format SERVQUAL: an experimental approach. *Journal of Business Research 49*: 57-65. http://dx.doi.org/10.1016/S0148-2963(98)00119-2

Conington J, Bishop SC, Waterhouse A and Simm G 2004 A bio-economic approach to derive economic values for pasture-based sheep genetic improvement programs. *Journal of Animal Science 82*: 1290-1304

Dwyer CM and Bornett HLI 2004 Chronic stress in sheep: assessment tools and their use in different management conditions. *Animal Welfare 13*: 293-304

Dwyer CM and Lawrence AB 2008 Introduction to animal welfare and the sheep. In: Dwyer C (ed) *The Welfare of Sheep* pp 1-39. Springer: Heidelburg, Germany. http://dx.doi.org/10.1007/978-1-4020-8553-6_1

FAWC 1994 *Report on the Welfare of Sheep*. FAWC: London, UK. http://www.fawc.org.uk/pdf/old/sheep-report-apr1994.pdf

Foresight 2011 The Future of Food and Farming. *Final Project Report*. The Government Office for Science: London, UK

Gill M, Smith P and Wilkinson JM 2010 Mitigating climate change: the role of domestic livestock. *Animal 4*: 323-333. http://dx.doi.org/10.1017/S1751731109004662

Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Pretty J, Robinson S, Thomas SM and Toulmin C 2010 Food security: the challenge of feeding 9 billion people. *Science 327*: 812-818. http://dx.doi.org/10.1126/science.1185383

Green P and Srinivasan V 1990 Conjoint analysis in marketing: new developments with implications for research and practice. *Journal in Marketing Oct*: 3-19. http://dx.doi.org/10.2307/1251756

Hanley N, Kirkpatrick H, Oglethorpe D and Simpson I 1998 Paying for public goods from agriculture: an application of the provider gets principal to moorland conservation in Shetland. *Land Economics 74*: 102-113. http://dx.doi.org/10.2307/3147216

Keeling L and Veissier I 2005 Developing a monitoring system to assess welfare quality in cattle, pigs and chickens. *Science and Society Improving Animal Welfare. Welfare Quality® Conference Proceedings* pp 46-50. Brussels: Belgium

Lawrence AB and Stott AW 2009 Profiting from animal welfare: an animal-based perspective. *Journal of the Royal Agricultural Society of England 170*: 1-8

Matthews K, Wright I, Buchan K, Davies D and Schwarz G 2006 Assessing the options for upland livestock systems under CAP reform: developing and applying a livestock systems model within whole-farm systems analysis. *Agricultural Systems 90*: 32-61. http://dx.doi.org/10.1016/j.agsy.2005.10.008

McInerney J 2004 Animal welfare economics and policy. *Report on a study undertaken for the Farm & Animal Health Economics Division of Defra.* Defra: London, UK

Parasuraman B, Zeithaml VA and Berry LL 1988 SERVQUAL: a multiple-item scale for measuring customer perceptions of service quality. *Journal of Retailing 64*: 12-40

Reed MS, Bonn A, Slee W, Beharry-Borg N, Birch J, Brown I, Burte TP, Chapman D, Chapman PJ, Clay GD, Cornelli SJ, Fraser EDG, Glass JH, Holden J, Hodgson JA, Hubacek K, Irvine B, Jing N, Kirkby MJ, Kunini WE, Moore O, Moseley D, Prell C, Price MF, Quinn CH, Redpath S, Reid C, Staglo S, Stringerd LC, Termansend M, Thorpp S, Towers W and Worrall F 2009 The future of the uplands. *Land Use Policy 26S1*: S204-S216

Rekom Van J and Wierenga B 2007 On the hierarchical nature of means-end relationships in laddering data. *Journal of Business Research 60*: 401-410. http://dx.doi.org/10.1016/j.jbusres.2006.10.004

SAC 2008a *Farming's Retreat from the Hills.* SAC, Rural Policy Centre: Edinburgh, UK. http://www.sac.ac.uk/mainrep/pdfs/retreatfromhillsfullreport.pdf

SAC 2008b *Farm Management Handbook 2008/9*. SAC: Edinburgh, UK

Stott AW, Milne CE, Goddard PJ and Waterhouse A 2005 Projected effect of alternative management strategies on profit and animal welfare in extensive sheep production systems in Great Britain. *Livestock Production Science 97*: 161-171. http://dx.doi.org/10.1016/j.livprodsci.2005.04.002

Stott AW, Vousough-Ahmadi B, Morgan-Davies C, Dwyer CM, Goddard P, Phillips K, Milne CE, Kupiec B, Ringrose S and Waterhouse A 2009 Evaluating extensive sheep farming systems. *Aspects of Applied Biology 93*: 161-166

Turner SP and Dwyer CM 2007 Welfare assessment of extensive animals: challenges and opportunities. *Animal Welfare 16*: 189-192

Vosough Ahmadi B, Stott AW, Baxter EM, Lawrence AB and Edwards SA 2011 Animal welfare and economic optimisation of farrowing systems. *Animal Welfare 20*: 57-67

Williams HP 2008 *Model Building in Mathematical Programming, Fourth Edition*. Wiley: Chichester, UK

https://doi.org/10.7120/096272812X13345905673683 Published online by Cambridge University Press