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Impacts of labour on interactions between economics and animal welfare in extensive sheep farms

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Summary

This study quantified interactions between animal welfare and farm profitability in British extensive sheep farming systems. Qualitative welfare assessment methodology was used to assess welfare from the animal's perspective in 20 commercial extensive sheep farms and to estimate labour demand for welfare, based on the assessed welfare scores using data collected from farm inventories. The estimated labour demand was then used as a coefficient in a linear program based model to establish the gross margin maximising farm management strategy for given farm situations, subject to constraints that reflected current resource limitations including labour supply. Regression analysis showed a significant relationship between the qualitative welfare assessment scores and labour supply on the inventoried farms but there was no significant relationship between current gross margin and assessed welfare scores. However, to meet the labour demand of the best welfare score, a reduction in flock size and in the average maximum farm gross margin was often required. These findings supported the hypothesis that trade-offs between animal welfare and farm profitability are necessary in providing maximum animal welfare via on-farm labour and sustainable British extensive sheep farming systems.

Keywords: Sheep, Labour, Animal Welfare, Linear Programme

JEL codes: C6, Q10, Q19, Q57

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Introduction

Good health and welfare of farmed animals were identified as major contributors to the sustainability of the livestock industry in Great Britain (Defra, 2004). Safeguarding the welfare of sheep in extensively managed systems requires significant labour, stockmanship and management inputs. In these systems, the available on-farm labour is mainly focused on key events at particular times of year such as providing appropriate nutrition to the pregnant ewes, care at lambing, shearing, gathering and activities related to the control and treatment of diseases (Goddard *et al.,* 2006). As a result, labour availability has been identified as one of the key factors influencing both welfare and financial productivity of these systems. However, there are grounds for concern as the availability of on-farm skilled labour is increasingly reduced and the labour pool of the skilled labour in extensive sheep production diminishes (Goddard *et al.,* 2006).

A decrease in labour can potentially have a significant detrimental impact on welfare, particularly in extensive systems where sheep receive considerable support from human intervention (Dwyer, 2009). A pre-CAP reform study showed a negative relationship between average financial margin and average welfare score in British extensive sheep farming systems (Stott *et al.,* 2005). Recent and future CAP reforms impose even more financial pressure on these farms to reduce input costs including the inputs of skilled labour, which may compromise animal welfare. For research-informed policy that reduces growing concern for the future of extensive sheep farming systems, decision makers need detailed information about the interactions between welfare and profitability.

There is a great lack of detailed quantitative information on task-based labour requirements/demands for adequate care and welfare of sheep in extensive systems. Nix (2008) only reports generic average monthly labour requirements across all sheep farming systems in the UK. An exception to this is a recent study by Kirwan *et al.* (2009) who quantified sheep labour demand to perform essential tasks during the lambing period in commercial extensive sheep farms. Beside this, little research has been done on assessing farm animal welfare under extensive conditions. Thus, welfare assessment methodologies need to be developed to ensure the recent changes in farming practices and labour supply in the extensive systems do not infringe on animal welfare (Dwyer, 2009).

In this study, a qualitative welfare assessment methodology was devised and used to assess welfare from the animal's perspective in a sample of extensive sheep farms in Great Britain and hence to estimate labour demand based on the assessed welfare scores. The estimated labour demand was then used in a linear programming (LP) model to establish the gross margin maximising farm management strategy for given farm situations subject to constraints that reflect the main resource limitations.

The objective was to assess the nature and extent of interactions between animal welfare and farm profitability in British extensive sheep farming systems and so assess the potential constraints on the development of sustainable agriculture in this sector. The details of the qualitative welfare assessment and linear programming model are presented and the basic results along with sensitivity analysis are shown.

The model is then used to analyse the impacts of labour supply and demand on possible interactions between financial margin and animal welfare.

Materials and methods

Input data

Input data for the linear programming model were collected from 20 extensive sheep farms chosen from a network of farmer focus groups established under Defra project AW1024 (SAC, 2009). These farms were geographically based in hill and upland areas of the Great Britain, namely the Peak District, Mid-Wales, Cumbria and North West Scotland. Equal numbers of farms were inventoried in each area. The data included a detailed inventory of resources, resource deployment and technical performances as well as qualitative profiles of farmers and in-depth interviews with the farmers concerned. Quantitative data from the inventories were used to represent each farm in a linear programme model. Available hill, pasture and hay producing land areas along with the monthly labour profile (i.e. labour supply) of the studied farms were directly used in the models. Farm specific technical performance data were used to calculate the annual gross output and gross margin per sheep. Calculated gross margin was then directly used in the models. Table 1 summarises the input data on land and technical performance and Table 2 presents the monthly labour profiles of the inventoried farms, which were calculated on a per ewe basis based on the flock sizes recorded in the inventories.

Qualitative welfare assessment

Keeling and Veissier (2005) have identified 12 specific welfare criteria that must be addressed by set of measures to assess animal welfare in a given system. Two of these criteria were specifically related to the housing in intensively managed systems and therefore were omitted from our list. Thus, for extensive sheep farms, it was considered that good sheep welfare from the animal perspective should address 10 specific welfare needs. The welfare criteria assessed were absence of prolonged hunger and thirst, physical comfort, pain, normal social behaviour, human-animal relationship, negative emotions, positive emotions, specific welfare knowledge/stockmanship, health-injuries and health-disease.

To generate welfare assessment scores, a qualitative welfare assessment approach was devised whereby the ability of each farm to meet the 10 sheep welfare needs was assessed by experts using a ‘visual analogue scoring scale’ (Wewers M.E. and Lowe N.K., 1990). Information and data gathered on farm management in the inventories were converted into a set of descriptions for all of the inventoried farms to present the complex information in a more readable form. The ability of each farm to meet 10 sheep welfare needs was assessed by a sheep welfare expert panel consists of 12 experts including three consultants, four sheep farmers, three veterinary surgeons and two welfare experts. Experts were asked to answer a questionnaire consisting of 37 statements scored on a 7-point scale that represented their degree of agreement (or disagreement) with the actual state of animal welfare on each farm being assessed. Each expert provided an assessment of welfare of every farm on each of the 10 welfare criteria, generating 2400 welfare scores, based on the provided descriptions.

Sheep labour demand

The monthly supplied labour on each farm was recorded in the inventory and it was converted to a per ewe basis to be used in the LP (see Table 2). However, the equivalent figure needed to meet the ewes' demands for labour was not known. It was hypothesised that qualitative welfare assessment score was dependent on key attributes of the studied farms such as available land areas, available on-farm labour as well as productivity. In other words qualitative assessment score was considered as the response variable that was dependent on the above-mentioned independent variables. Therefore, a multiple linear regression analysis (Snedecor, 1956) was used to establish the relationship between qualitative welfare assessment score and key attributes drawn from the farm inventories. As a first approximation, with the independent variables consisting of labour supplied in hours/ewe/year, in-bye land (better quality land close to the farmstead) per ewe (Ha), hill land per ewe (Ha) and ewe performance (lambs weaned/ewe) a multiple regression procedure was used, with the objective of finding the variables that best fit the welfare assessment scores. Table 3 presents the results of this analysis. The resulting regression equation is as follows:

$$y = 4.59 + 1.44x_1 + 1.90x_2 - 0.05x_3 + 1.06x_4 \quad (1)$$

where y represents qualitative welfare assessment score, x_1 is labour supplied, x_2 is in-bye land, x_3 is hill land and x_4 is ewe performance. The coefficient of multiple determinations, R^2, explained 0.56 of the variation in y (F statistic 7.1; $p<0.003$) where y reflected the average of nine needs scores i.e. all but 'normal social behaviour' (the only score that was not highly correlated with the others and therefore unsuitable for inclusion in an aggregate score) as described in the previous section. Farm specific data were then fitted to the equation and 'fitted welfare scores' were determined. Figure 1 presents the assessed welfare scores and 'fitted welfare scores' of the 20 studied farms. By setting y in equation 1 to the maximum fitted value of 8.3 (i.e. the best-fitted welfare score; see Figure 1) and solving it for x_1 (i.e. labour), the labour demand for each farm was estimated. Each inventory farm's value of x_1 was then allocated to months' pro-rata using the distribution of labour supply recorded in the inventory by the farm concerned (Table 2). These values were used as labour demand per ewe coefficient in the LP (Table 4). For further details see the final report of project AW1024 (SAC, 2009).

Linear programming model

The mathematical model used in the Defra project AW1024 (SAC, 2009) was a multi period (monthly) LP for a typical sheep farming year with the objective of maximising enterprise gross margin subject to balancing supply of nutrients (grass and silage/hay) with sheep nutritional demand together with other constraints. Nutritional demand was based on established relationships between feed energy intake and sheep production (AFRC, 1993). General structure of the model, which follows the standard format of LP models (Bernard and Nix, 1979), is presented in Table 4 and can be summarised as:

$Maximise(Z = c'x)$

Subject to $Ax \leq b$

And $x \geq 0$

where *Z* is the farm gross margin, *c* denotes the vector of gross margin or cost/revenue per unit of activity, *x* denotes the vector of activities, *A* represents the matrix of technical coefficients and *b* is the technical or physical constraints. Grass feed energy supply was based on the model of Armstrong *et al.* (1997).

Only the ewe flock was modelled as the main economic activity of the farms, yet all of the inventory farms finished at least some of the lambs surplus to requirements as replacements (Table 1). A set of average lamb values at sale presented in Table 5, and the output generated from the sold draft ewes at sale price of £25/head were incorporated in the gross outputs shown in Table 1. Any extra resources required for lamb finishing were not otherwise accounted for.

The sheep labour demand, which was estimated based on the qualitative welfare scores using multiple regression analysis, were aligned in the LP with the monthly supply of labour estimated for each farm in the farm inventory (Table 2). To explore the impact of these labour constraints on the farm plan extra labour supply activities (i.e. casual labour, see Table 4) for each month were introduced so that the constraints could be relaxed by the LP if farm gross margin was thereby increased.

Model output

The solution of the model provides a maximised farm gross margin, the number of ewes; a feeding and grazing pattern across different land areas including hill, pasture and forage producing areas along with annual dry matter intake and the monthly casual labour utilised.

Model validation

Initial parameters for the LP were based on Conington *et al.* (2004) to represent extensive hill sheep farming systems typical in Great Britain. To validate the model in representing the upland and hill farms included in this study, parameters were modified to reflect the physical conditions of farm and sheep flock at Kirkton, SAC's Hill and Mountain Research Centre farm at Crianlarich of (SAC, 2010). Optimal plan including the physical and financial performance of the flock and the grazing management were checked with the Head of Centre and adjustments were made to mimic special features of the farm plan. Details of validation are given in the annex to the final report of project AW1024 (SAC, 2009).

Model runs

Three main runs of the LP were undertaken for each of the 20 inventory farms. The three runs were as follows: *Run 1)* The optimum (gross margin maximising) farm plan established with parameters and constraint boundaries set to reflect current values as supplied in the farm inventory but with capacity to draw down extra (or casual) labour as required without cost. *Run 2)* Flock size reduced from current values by set increments 0.9, 0.75, 0.5, 0.25 and 0.1 to find the approximate point where labour currently available on the farm is sufficient to cover the predicted demand for labour (see section 2.3). Comparison with run 1 then provides an indication of the change in farm plan and farm gross margin etc. necessary to attain a maximum predicted welfare score from labour. *Run 3)* In this run the system was allowed to hire casual labour (if profitable) and the price of the casual labour needed to meet labour demand was set to £5/hour.

Results

Welfare scores

Mean scores given for each welfare need are shown in Figure 2 and demonstrate that on average extensive sheep farms provided welfare needs that scored above the mid-point for each criterion. Significantly lower welfare scores were given for the criteria 'pain' and 'negative emotions' than for other welfare needs (Figure 2, $P<0.001$). Scores given ranged from 1.1 to 10.7 suggesting that experts were using the full range of the scale in their assessments. Further investigations revealed that there were two main axes of welfare, with 'normal social behaviour' (need number 4 in Figure 2) grouping differently to all the other welfare criteria. Thus, as 'normal social behaviour' criterion disassociated from other welfare scores it was excluded from our methodology used to determine the monthly labour demand of sheep from the assessed welfare scores to be used in the LP (see section *Sheep labour demand*).

LP runs

In run 1, with no constraint on labour supply, no significant relationship was found between maximum farm gross margins or gross margin per ewe predicted by the LP and welfare scores (Figure 3a and 3b). Average maximum gross margin was £8.9±0.5 per ewe (Table 6). However, farms with the highest qualitative assessment welfare required significantly less casual labour to meet the welfare related labour constraint than other farms (Figure 4). Six farms had sufficient or excess on-farm labour supply (either regular or casual labour) to meet predicted labour demand. Approximately 0.52 of the variation observed in overall welfare scores were explained by the average difference between regular and casual labour supply (Figure 5).

Although gross margins and welfare scores were unrelated in run 1, reducing flock size in run 2 to match predicted labour requirements for maximum welfare score with on-farm labour supply, reduced the average maximum gross margin across all focus farms from £6424±751.6 to £2614±458.7 (Figure 6). However, the (unpaid) casual labour saved by this change was on average 7377±2074 hours. Four farms had sufficient on-farm labour supply to meet predicted labour demand and therefore required no flock size adjustments or change in gross margin to meet this welfare constraint. Introducing the possibility of hiring costly casual labour in run 3 led to a higher flock size and generated higher gross margins compared to run 2. The average farm gross margin in run 3 was £3172±444 generated from a herd size of 318±73 (Figure 6).

Discussion and conclusions

The aim of the analysis presented in this paper was to examine the impacts of on-farm labour availability on interactions between profit and welfare in extensive sheep farming systems. Given the complexity of the issues involved in extensive systems such as farm management, nutritional requirements of animals, grazing patterns, human-animal interactions, animal welfare, dynamic on-farm labour supply/demand, we could not achieve this objective without simplifying these systems by using some assumptions and applying some analytical techniques such as multiple regression analysis.

This method was used to estimate labour demand of sheep in the situation where there is a great lack of knowledge and quantitative information on the actual labour demand of sheep in order to deliver an appropriate level of welfare. The presented analysis provided an aspiration for labour demand, based on the variation in overall welfare score adjusted for other factors (i.e. labour supplied, in-bye land, hill land and ewe performance) that affect score. Farms where other factors contributed towards a higher welfare score would have a relatively low labour demand. Where these factors were deficient, a relatively high labour demand would be required. Despite the reasonably good fit of the regression equation, this is clearly a crude estimate of the trade-offs between farm attributes that might contribute to overall welfare. Direct observation of labour demand of sheep based on the tasks performed to deliver different welfare attributes to animals is the best alternative to get the quantitative data required for such models.

In general the nutritional LP model which related energy demand of the sheep to the supplied feed from the available resources, provided us with a means to investigate the relationships between demand and supply of farm labour with the financial outcomes of the extensive farms. Although no significant relationship between the welfare score and enterprise gross margin was observed, farms with the highest welfare score required significantly less casual labour to meet the welfare related labour constraint than other farms. This finding suggests that such farms have better matched existing labour deployment to the needs of the sheep enterprise, are less reliant on external labour and hence are more likely to maintain required standards of welfare and profitability.

Results showed that to meet the highest achievable welfare with respect to the sheep labour demand, by utilising current on-farm labour supply, a significant reduction in flock size and inevitably in gross margin is often required. In these cases, casual labour charged at £5/hour (approximate minimum wage) was not justified to maintain flock size in the face of savings that could be made by reducing flock size and altering the feeding regime. In theory, slack existing farm labour may have an opportunity cost that could be realised, thus offsetting some of the income lost by flock size reduction. In practice however, this labour rarely exists and in any case labour requirements per ewe would not remain fixed (as assumed here) at the extremes of flock size reduction needed on some farms to meet labour demands.

It can be concluded that trade-offs between animal welfare and farm profitability do occur in British extensive sheep farming systems. However, between farm variation was considerable. Some farms required up to approximately 0.9 reduction in current flock size to meet labour demand for welfare, yet 0.2 of our sample were able to attain the highest welfare score at current flock size. Where extra labour was needed, this could not be justified at current minimum wage rates. It follows that unless the improvements in welfare associated with extra labour supply that were identified here are paid for, selective contraction of the industry is an inevitable consequence of sustainable British extensive sheep farming.

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Tables

Table 1. Input data including technical performance and available land areas for the 20 inventoried farms used in the LP.

	Inventoried farms in four areas of the Great Britain																			
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20
Number animals																				
Ewes	720	2000	850	1600	900	1150	350	645	530	2222	500	271	200	425	660	600	1600	752	420	600
Lambs weaned	800	1950	950	1900	1020	1250	350	900	700	1778	700	214	180	529	789	800	2800	806	400	836
Retained female lambs	200	975	180	500	248	350	110	150	110	500	100	78	60	130	223	0	300	170	90	203
Retained male lambs	20	40	0	0	6	5	0	0	0	0	0	0	15	5	4	0	6	2	3	3
Finished lambs sold	405	935	400	950	600	900	240	750	250	400	0	0	0	0	172	800	2490	634	227	670
Store lambs sold	0	0	250	0	80	0	0	0	90	0	600	117	105	394	261	0	0	0	80	0
Breeding lambs sold	175	0	100	450	78	0	0	0	0	0	0	0	0	50	150	0	250	156	180	50
Draft ewes sold	160	850	131*	300	300	0	0	0	90	0	100	49	30	40	156	100	0	32	40	131
Gross output (£/ewe)	24.6	23.6	24.6	26.6	25.6	25.9	26.1	25.7	24.5	24.5	24.8	24.3	23.3	23.4	24.3	30.5	27.0	25.5	24.9	25.9
Gross margin[1] (£/ewe)	14.0	13.0	14.0	16.0	15.0	15.4	15.5	15.1	13.9	13.9	13.6	13.7	12.7	12.9	13.7	19.9	16.4	14.9	14.3	15.3
Land area (ha)																				
Hill[2]	168	1400	470	627	550	1300	623	373	280	1900	4031	576	5694	4510	666	10	30	160	104	18
Pasture[3]	68	70	197	135	44	210	46	5	0	185	318	7	11	31	16	85	350	103	54	120
Hay land[4]	2.8	8.0	3.4	6.4	3.6	15	15	15	15	15	15	16	17	18	19	15	15	15	15	15

[1] Gross margin before ewe feeding

[2] Consists of open hill and intake (hill park) area

[3] Consists of true in-bye (i.e. improved land near farm buildings) minus estimated hay land area

[4] Assumed 0.004 ha/ewe (SAC, 2008)

Sale price of draft ewes (£/head): 25

Variable costs ex-feed from SAC (2008) of £10.58/ewe, page 171 Hill Breeding ewes-store lamb production-limited in-bye

* *Identified as missing in the original inventory data file; value was estimated by the authors based on an annual mortality rate of 4% and keeping the ewes for 6 years.*

Table 2. Monthly available on-farm labour profile data of the inventoried farms used as labour supply per ewe in the LP.

	Monthly labour supply (hours/ewe)											
Farm	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
F1	0.30	0.20	0.29	0.40	0.75	0.78	0.14	0.30	0.22	0.29	0.30	0.29
F2	0.25	0.25	0.22	0.28	0.30	0.34	0.36	0.37	0.37	0.36	0.31	0.27
F3	0.24	0.07	0.14	0.15	0.58	0.38	0.26	0.27	0.17	0.17	0.17	0.27
F4	0.17	0.17	0.12	0.16	0.17	0.19	0.21	0.21	0.21	0.21	0.19	0.17
F5	0.31	0.15	0.19	0.22	0.56	0.48	0.14	0.31	0.23	0.35	0.32	0.31
F6	0.02	0.08	0.12	0.96	0.92	0.06	0.07	0.11	0.05	0.06	0.04	0.05
F7	0.10	1.09	0.49	0.95	2.50	0.63	0.29	0.80	0.21	0.51	0.20	0.12
F8	0.27	0.44	0.50	2.55	2.47	0.44	0.93	0.92	0.52	0.69	0.82	0.53
F9	0.33	0.20	0.24	1.65	1.60	0.92	0.73	0.88	0.40	0.65	0.67	0.65
F10	0.10	0.02	0.13	0.07	0.29	0.25	0.12	0.06	0.06	0.08	0.06	0.04
F11	0.12	0.04	0.03	0.32	1.20	1.49	0.51	0.34	0.03	0.33	0.22	0.12
F12	0.17	0.05	0.16	0.17	0.17	0.52	0.05	0.05	0.00	0.05	0.00	0.03
F13	1.24	0.93	0.84	0.93	2.70	2.79	1.20	0.89	0.89	0.86	0.89	0.86
F14	0.44	0.44	0.40	0.58	2.68	2.77	0.85	0.88	0.58	0.66	0.58	0.42
F15	0.28	0.09	0.15	0.19	0.55	0.47	0.36	0.38	0.24	0.27	0.38	0.27
F16	0.29	0.13	0.12	0.19	1.45	0.67	0.35	0.15	0.20	0.38	0.39	0.35
F17	0.14	0.20	0.23	0.67	0.65	0.57	0.31	0.14	0.14	0.17	0.20	0.13
F18	0.04	0.16	0.14	0.20	0.71	0.25	0.05	0.14	0.12	0.24	0.14	0.04
F19	0.21	0.30	0.27	1.62	1.57	0.63	0.20	0.21	0.42	0.41	0.63	0.20
F20	0.21	0.14	0.21	0.16	1.80	0.41	0.40	0.41	0.31	0.30	0.31	0.20

Table 3. Linear regression model for prediction of welfare assessment scores using the independent variables drawn from the farm inventories.

	Regression	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
R square	0.655				
Adjusted R square	0.563				
Intercept		4.588	0.663	6.916	0.000
Labour supply		1.438	0.651	2.209	0.043
Inbye/ewe		1.904	1.072	1.776	0.096
Hill/ewe		−0.053	0.032	-1.663	0.117
Lambs/ewe		1.632	0.665	2.454	0.027

Table 4. Summarised* general representations of the sheep nutritional linear programming model**

Activities	Ewe	Consumption/grazing (DM/day)						Transfer energy from feed to sheep (MJ/day)						Land (Ha)			Grass prod (Ha)			Store hay	Transfer stored	Sell hay	Lab.	RHS
	E	H	P	A	Oh	Bh	C	H	P	A	Oh	Bh	C	H	P	S	H	P	S	Oh	Oh, S	Oh	CL	
Constraints																								
Max DM intake	$+a_{ij}$	-1	-1	-1	-1	-1	-1																	≥0
ME demand	$+a_{ij}$							-1	-1	-1	-1	-1	-1											≤0
ME Hill Grass		$-a_{ij}$						1																=0
ME Pasture			$-a_{ij}$						1															=0
ME Aftermath				$-a_{ij}$						1														=0
ME Own hay					$-a_{ij}$						1													=0
ME Bought hay						$-a_{ij}$						1												=0
ME Concentrate							$-a_{ij}$						1											=0
Max Concentrate		$-a_{ij}$	$-a_{ij}$	$-a_{ij}$	$-a_{ij}$	$-a_{ij}$	$+a_{ij}$																	≤0
Max sheep	1																							≤Max
Hill supply		1															$-a_{ij}$							≤0
Max Hill														1										≤Max
Pasture supply			1															$-a_{ij}$						≤0
Max Pasture															1									≤Max
Aftermath supply				1															$-a_{ij}$					≤0
Max hay land																1								≤Max
Tie Own hay																			$-a_{ij}$	$+a_{ij}$				≤0
Use store hay					$+a_{ij}$															-1	$\pm a_{ij}$	1		≤0
Tie Hill to prod														-1			1							≤0
Tie Pasture prod															-1			1						≤0
Tie Hay to prodn																-1			1					≤0
Labour	$+a_{ij}$																						-1	≤Max
Objective function	Gross margin £/head											Cost £/kg		Cost £/ha								Revenue £/kg	Cost £/hr	

a_{ij} the technical coefficient that relates activity *I* to the constraint *j*.

* In the actual model daily energy demand and feed supply was modelled in a *monthly* basis throughout a farming year.

** Notations: E: Ewes; H: Hill; P: Pasture; A: Aftermath; Oh: Own hay; Bh: Bought hay; C: Concentrate; S: Silage; CL: Casual Labour; RHS: Right-hand side constraints.

Table 5. Average lamb values[1] across the farms in each area.

	Scotland	*Wales*	*Peak district*	*Cumbria*
Lamb values at sale £/head in 2007	27.08	29.22	28.58	28.38

[1] Including an extra £2.61 as the added margin obtained from lambs retained for finishing (based on SAC, 2008).

Table 6. Output of run 1 including predicted flock size, gross margin, feed intake and casual labour of 20 farms and average and standard errors.

		Gross Margin (£)		Dry mater intake (kg/ewe/year)						Labour (hr/ewe)
Farm	Number of ewes	Farm	Ewe	Hill grazing[1]	Pasture grazing[1]	Aftermath grazing[1]	Own hay[2]	Bought hay[3]	Concentrate[4]	Casual labour[5]
F1	720	5507	7.6	92	176	9	54	6	0	10
F2	1368	8081	5.9	172	109	13	28	37	0	12
F3	850	6999	8.2	182	84	20	50	11	0	9
F4	1600	15938	10.0	164	121	15	24	42	0	11
F5	900	9806	10.9	214	58	17	47	15	0	11
F6	1150	9520	8.3	198	78	10	21	46	0	11
F7	350	3763	10.8	174	55	46	68	0	0	7
F8	580	4669	8.1	190	42	25	41	53	0	0
F9	262	2408	9.2	243	0	18	90	0	0	0
F10	2222	10662	4.8	129	154	9	11	56	0	18
F11	500	6068	12.1	373	22	7	15	0	0	0
F12	271	3053	11.3	330	21	7	34	0	0	17
F13	200	2247	11.2	387	16	1	15	0	0	12
F14	425	4849	11.4	373	29	1	15	0	0	4
F15	660	5985	9.1	181	101	24	36	10	0	9
F16	600	6390	10.6	17	192	53	40	33	0	6
F17	1600	9288	5.8	22	219	26	15	52	0	0
F18	752	5828	7.8	135	109	27	32	40	0	12
F19	420	3661	8.7	139	99	49	56	6	0	9
F20	600	3755	6.3	35	172	53	40	32	0	4
Average	802	6424	8.9	187	93	21	37	22	0	8
SE	119	752	0.5	25	14	4	5	5	0	1

[1] Quality of grazing varied throughout the year based on ARC (1976)
[2] ME 8MJ/kg, DM 850 g/kg
[3] ME 9MJ/kg, DM 850 g/kg, £70/t fresh
[4] ME 12 MJ/kg, DM 850 g/kg, £250/t fresh
[5] No extra costs of casual labour (£0/hr)

Figures

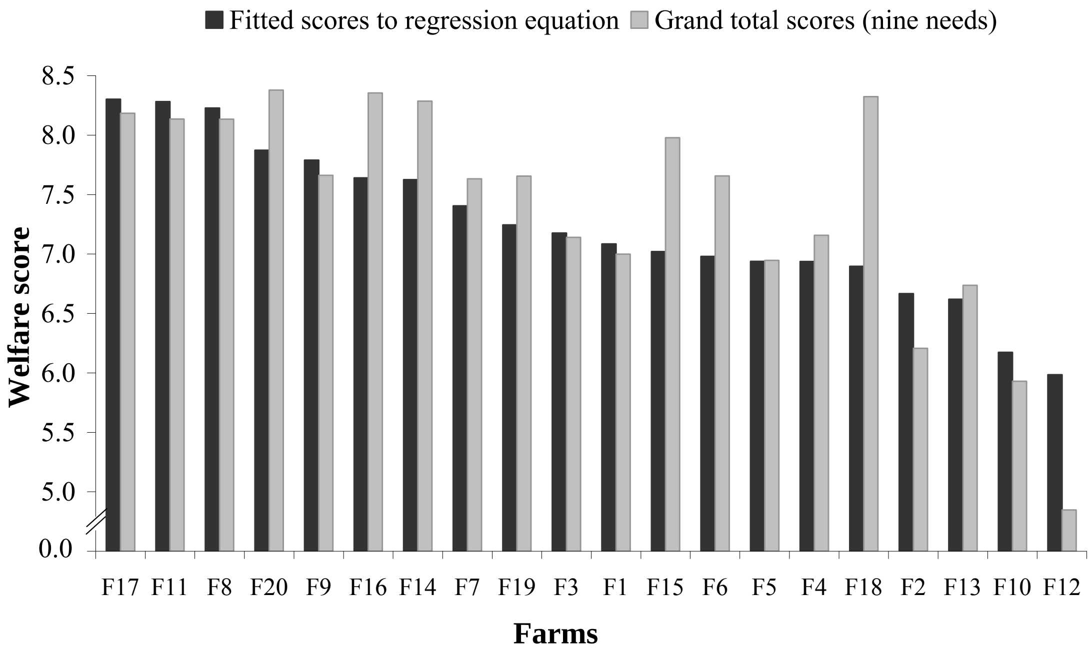

Figure 1. Welfare scores fitted to the regression equation (1) and average of grand total welfare scores for nine needs of the 20 studied farms.

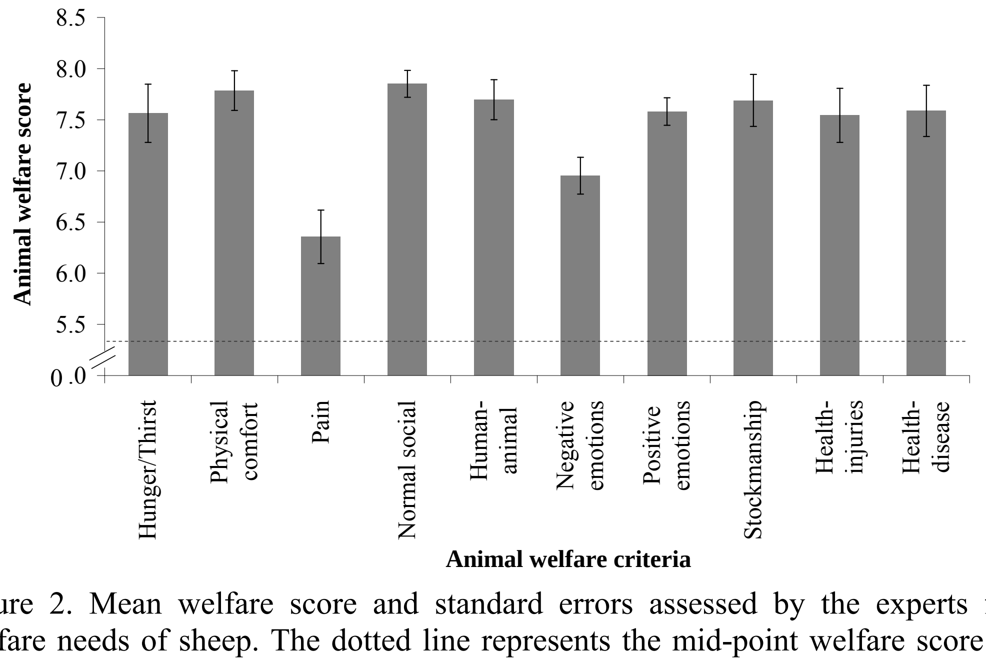

Figure 2. Mean welfare score and standard errors assessed by the experts for 10 welfare needs of sheep. The dotted line represents the mid-point welfare score at 5.3 for each welfare need.

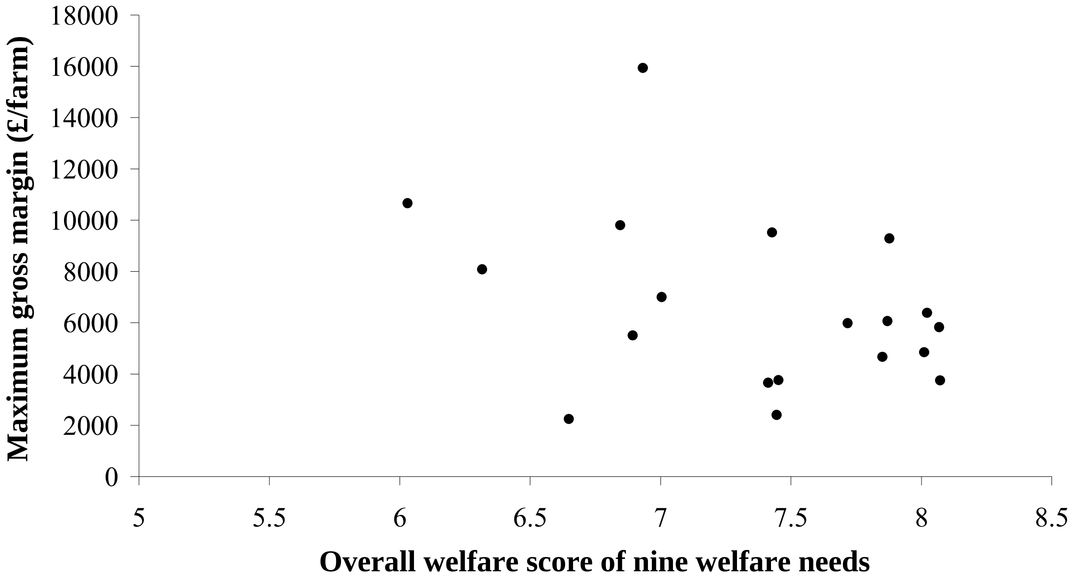

Figure 3a. Maximum gross margin (£/farm) predicted by the LP and average overall welfare scores assessed by experts for the 20 studied extensive sheep farms in Great Britain.

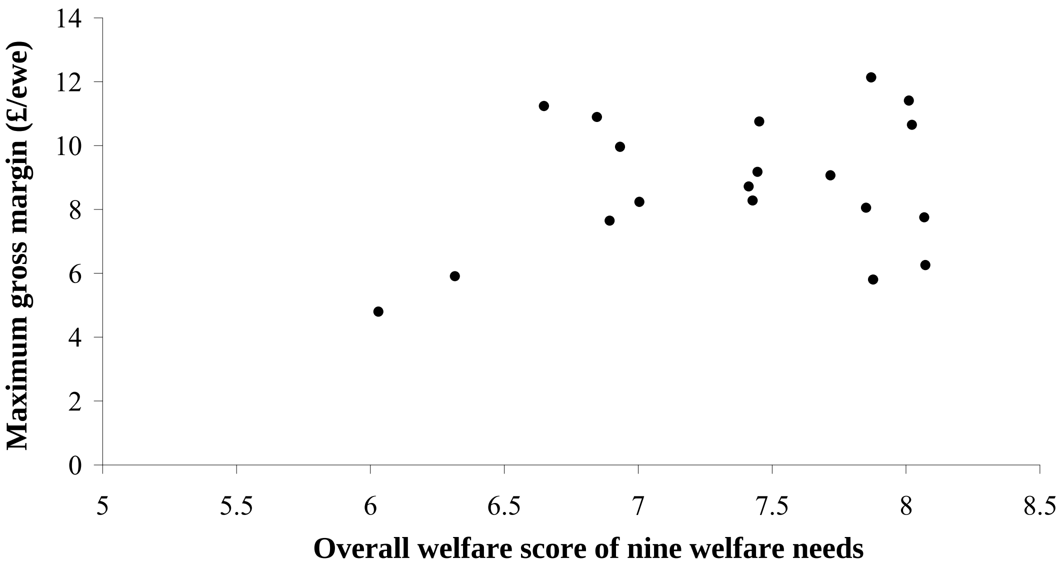

Figure 3b. Maximum gross margin (£/ewe) predicted by the LP and average overall welfare scores assessed by experts for the 20 studied extensive sheep farms in Great Britain.

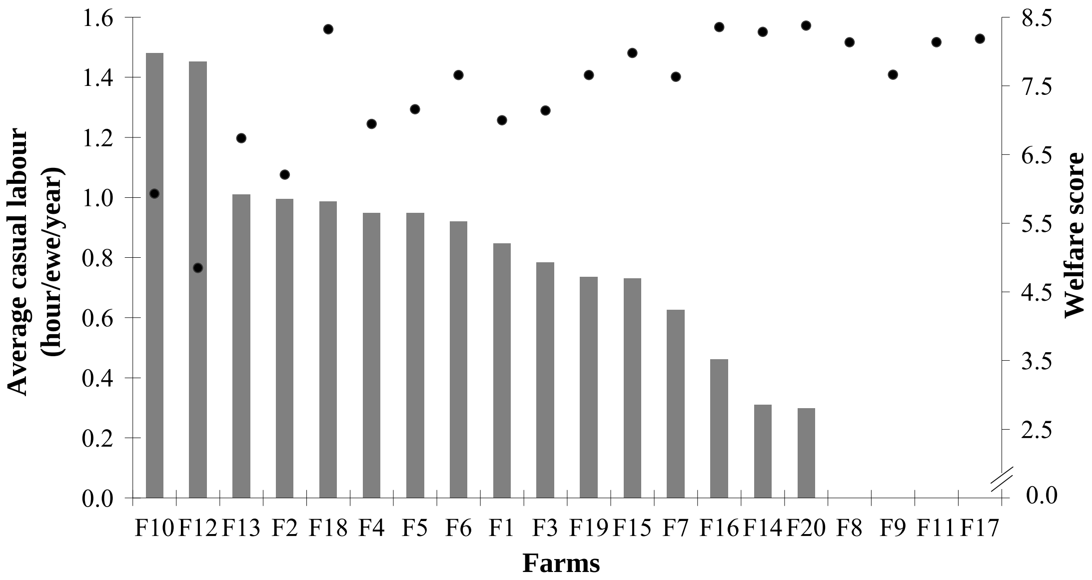

Figure 4. Average annual utilised casual labour per ewe (bars) in optimal plan by the model and associated grand total welfare scores for nine needs (dots) of the 20 studied farms.

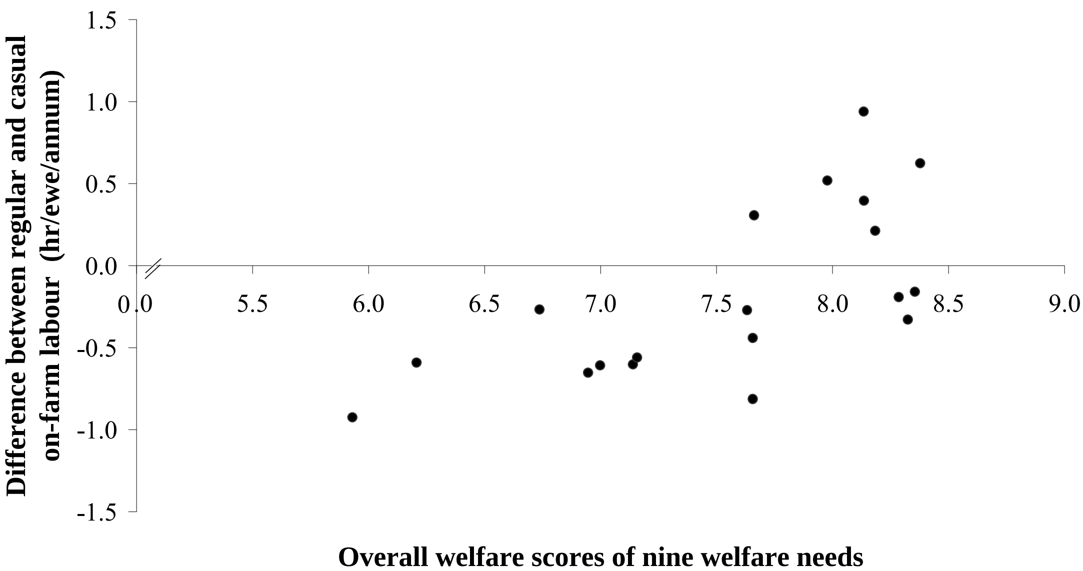

Figure 5. Difference between regular and casual on-farm labour (vertical axis) and grand total welfare scores for nine needs (horizontal axis). The slope of the regression line fitted was 0.45 with the adjusted R^2 of 0.52 (F statistic 21.6; p<0.001).

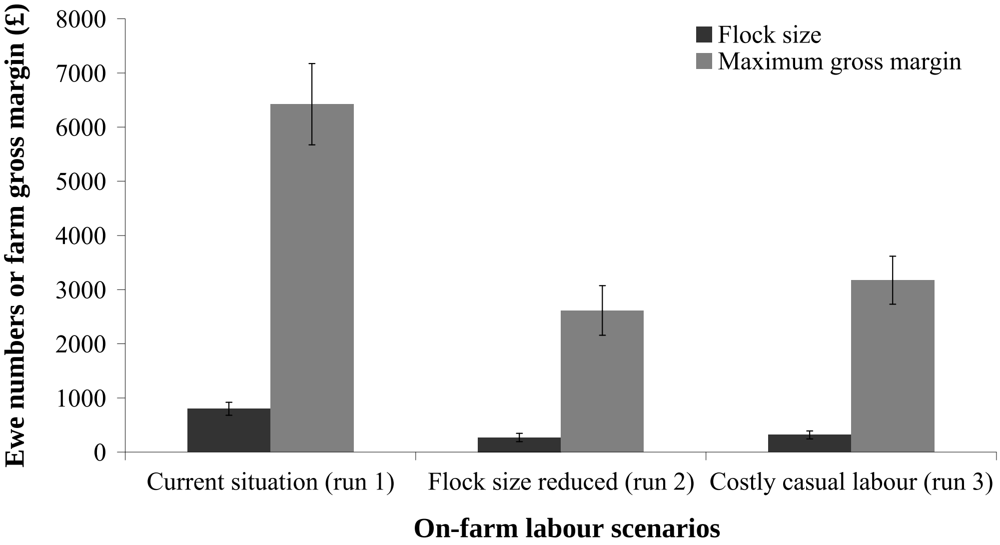

Figure 6. Average flock size and farm gross margin in 20 studied extensive sheep farms in the GB in run 1 (casual labour hired at £0/hr to meet labour demand), run 2 (flock size reduced to match the own labour supply and sheep labour demand) and run 3 (casual labour hired at £5/hr).