Estimating utility functions of Greek dairy sheep farmers: A multicriteria mathematical programming approach

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Abstract
Mathematical programming models are commonly used to approach decision making in livestock farms. The majority of these models assume gross margin maximisation as the sole objective of farmers. In this study an alternative multicriteria model is built to test the hypothesis of the multiplicity of the objectives of Greek sheep farmers. A farm typology is constructed to account for diversified farm structures and a non-interactive methodology is used to elicit the utility function of farmers. The results of the analysis indicate that the multicriteria model allows for a better representation of the farms, compared to the gross margin maximisation model.
Keywords: *sheep farming, multicriteria analysis, mixed integer programming, utility function, weights*

Introduction

Mathematical programming models are commonly used to capture livestock farmers' decision making (e.g. Veysset et al., 2005; Crosson et al., 2006). Their main advantage is that they allow for an accurate technico-economic representation of the farms and take into account interrelationships and physical linkages between alternative production activities.

Traditionally, optimisation models assume that gross margin maximisation is the sole objective of farmers. However, many studies have underlined the existence of multiple objectives in agriculture, linking them to the development of diversified farm structures and alternative management strategies (Gasson, 1973; Cary & Holmes, 1982; Fairwheather & Keating, 1994; Solano et al., 2001). Mathematical programming models that ignore farmers' multiple objectives may therefore be less effective or even misleading for policy analysis purposes.

On the other hand, the theoretical dispute on the multiplicity of objectives has encouraged the development of methodologies, such as multicriteria analysis, that attempt to incorporate these objectives in mathematical programming models. In the majority of these multicriteria approaches, the goals incorporated in the model and the weights attached to them are elicited through an interactive process with the farmer. However, this interaction has many limitations, such as farmers' difficulty to explicit goals and to avoid interviewer influence.

In this analysis a non-interactive technique proposed by Sumpsi et al. (1996) and further extended by Amador et al. (1998) is applied to elicit the individual utility functions of Greek sheep farmers. This methodology has recently been used to estimate impacts of irrigation water pricing in Greece (e.g. Manos et al., 2006; Latinopoulos,

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2008). To account for the heterogeneity of the sheep farming activity in terms of farm structure and management, multivariate analysis is performed to develop a farm typology. Results of our analysis indicate the superiority of the multicriteria model compared to the traditional, single objective one and support the usefulness of the methodology to researchers and policy makers.

This paper is organised as follows. First, the multicriteria methodology is presented. Next, the case study is discussed and specifications on the farm typology, the model and the farmer objectives used in the analysis are provided. The last two sections contain the results of the analysis and some concluding remarks.

Methodology

The first step of the non-interactive process is to define an initial set of objectives $f_{1(x)},\ldots,f_{i(x)},\ldots,f_{q(x)}$ and to obtain the pay-off matrix by means of consecutive optimizations within the farm model feasible area. The elements of the pay-off matrix and the actual values of objectives are then used to build the following system of q equations that provides the weights of the objectives:

$$\sum_{j=1}^{q} w_j f_{ij} = f_i \qquad i = 1,2,...,q \qquad (1)$$

$$\sum_{j=1}^{q} w_j = 1$$

where: w_i : weight attached to the i-th objective, f_{ij} : value achieved by the i-th objective when the j-th objective is optimised, f_i : observed value of the i-th objective.

Usually, the above system of equations has no non-negative solution. Thus, the best solution is alternatively approximated, using the concept of L metrics to minimise the corresponding deviations from the observed values. When combining L_1 and L_∞ metrics, a linear specification is formed and solved (Amador et al., 1998):

$$Min D + \lambda \sum_{i=1}^{q} \left(\frac{n_i + p_i}{f_i}\right) \text{ subject to:} \qquad (2)$$

$$\sum_{j=1}^{q} w_j f_{ij} + n_i - p_i = f_i \qquad i = 1,2,...,q \qquad (3)$$

$$\sum_{j=1}^{q} w_j f_{ij} + f_i D \geq f_i \qquad (4)$$

$$-\sum_{j=1}^{q} w_j f_{ij} + f_i D \geq -f_i \qquad (5)$$

$$\sum_{j=1}^{q} w_j = 1 \qquad (6)$$

Beside weights (w), variables include n_i : negative deviation (underachievement of the i-th objective with respect to a given target), p_i : positive deviation (overachievement of the i-th objective with respect to a given target), D : largest deviation of the i-th objective with respect to a given target. The parameter λ denotes the degree of substitution among objectives in the utility function.

The weights obtained by the above linear programming problem are used to derive the utility function of the farmer which has the following form:

$$u = -Max\left\{\frac{w_i}{k_i}\left[f_i^* - f_i(x)\right]\right\} + \lambda\sum_{j}^{q}\frac{w_i}{k_i}f_i(x) \qquad (7)$$

where k_i is a normalising factor used when objectives are measured in different units. Depending on the value of the parameter λ, different utility functions are generated. If λ=0, then u becomes a Tchebycheff function, which implies a complementary relationship between objectives. In this case as can be seen in (2), only the largest deviation D is minimised subject to (4), (5) and (6). When λ takes a large value, u is a separable and additive utility function. According to (2), the sum of the positive and negative deviational variables is minimised subject to (3) and (6). For small values of λ, u becomes an augmented Tchebycheff function (Amador et al., 1998).

The next step of the methodology is to validate the model, i.e. to verify that the utility function can accurately reproduce farmers' behaviour. For the maximisation of the utility, the following problem is formed and solved (Amador et al., 1998):

$$MinD + \lambda\sum_{i=1}^{q}\frac{w_i}{k_i}f_i(x) \text{ subject to} \qquad (8)$$

$$\frac{w_i}{k_i}\left[f_i^* - f_i(x)\right] \le D \quad i = 1,2,...,q \qquad (9)$$

$$\mathbf{x} \in \mathbf{F}$$

To identify the exact form of the utility function of the farmer the results obtained by the maximisation of (8) for various levels of λ, are compared with the actual values of the objectives.

Case study

Farm typology

The analysis is undertaken in different farm types identified using multivariate analysis techniques, to capture the heterogeneity of the Greek sheep farming activity. In order to perform multivariate analysis, farm-level, technico-economic data were used that were taken from a stratified random sample of 150 sheep farms located in three prefectures of Continental Greece (Etoloakarnania, Serres and Drama). The number of ewes was used for the stratification. The farm-level data refer to the agricultural year 2006-2007. In order to produce a farm typology, cluster analysis was implemented using 31 variables that described farm size, intensity, and production orientation (since the sheep farming activity often co-exists with other crop and livestock activities). Some characteristics of the farmer were also taken into account.

Factor analysis was initially conducted, to reduce the number of variables to a smaller set. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett test of sphericity indicate that there are sufficient correlations among the variables (KMO=0.68). The extraction method used was the Principal Component Analysis, which led to ten factors with eigenvalues greater than one that explained 79% of the total variance. For the interpretation of the factors the varimax rotation was used. The first two factors refer to the size of the farms. The next two factors refer to other crop and livestock activities of the sheep farms and the fifth factor refers to the intensity of the sheep farming activity. The other five factors refer to farmer characteristics, livestock nutrition, capital, non-agricultural activities and specialisation towards milk production.

The Ward's method of hierarchical cluster analysis was performed using the above factors to produce the farm typology. Intervals among cases were measured using squared Euclidean distance. The K-means cluster analysis was also performed to validate the results. The eight-cluster solution produces similar group membership using both analyses and was therefore adopted. The Kruskal-Wallis nonparametric test was also conducted to identify differences among clusters. The derived typology consists of six farm types, since two farms remained ungrouped (about 1% of the sample).

The first farm type consists of semi-intensive sheep farms (35% of the sample) with average farm size and milk production. The second farm type refers to part-time farmers with significant income from off-farm activities (9% of the sample). The third type represents 25% of the sample and refers to low productivity, extensive farms. The fourth type includes mixed crop-sheep farms (14% of the sample). The fifth farm type is highly productive can be characterised as intensive (7% of the total sample). The last farm type is the mixed livestock farm. It represents 9% of the sample and its main characteristic is the presence of other livestock activities like goat farming. The representative farm of each farm type is then selected and used further in the analysis. The main characteristics of these farms are presented in Tables 2-7 of the Appendix (last columns).

Model specification

The feasible space is determined by means of a whole-farm mixed-integer programming model. The decision variables of the model (x) refer to crop and livestock activities of the farms. Crop activities involve mainly feed production for livestock but also cash crops. Livestock activities refer mainly to per month sheep milk and lamb production. Decision variables that refer to monthly consumption of all purchased and produced feed as well as monthly hired and family labour are also incorporated in the model.

The model contains four sets of constraints. The first set involves monthly feed requirements, in terms of dry matter, net energy of lactation, digestible nitrogen and fiber matter. The second set of constraints balances monthly labour requirements of all production activities mainly with family labour inputs. Additional hired labour can be used, if necessary, in both livestock and crop activities. Land constraints ensure availability of the total area utilised by the various crop activities and of pasture land. A final set of constraints reflects the demography of the livestock and the maximum milk and lamb production per ewe.

Initial set of goals

In order to apply the multicriteria methodology an initial set of objectives must be defined. Five objectives have been used in this analysis, which were determined according to the literature and preliminary interviews with the farmers (see for example Barnett et al., 1982; Piech & Rehman, 1993; Berbel & Rodriguez-Ocaña, 1998; Wallace and Moss, 2002; Gómez-Limón et al., 2003). The first objective is the maximisation of gross margin (f_1), commonly used in agricultural studies. The second objective is the minimisation of risk (f_2), which has been approximated using the MOTAD approach (see Hazell, 1971). The third objective involves the minimisation of family labour (f_3). The fourth objective is the minimisation of variable cost (f_4), since the preliminary interviews indicate that farmers often place more value on keeping their expenses (mainly variable cost) low rather than making maximum profit. Finally, the fifth objective is the minimisation of the amount of purchased feed (measured in Mj) (f_5) which expresses farmer's attempt to benefit from vertical integration.

Results and discussion

The weights obtained for each representative farm and for various levels of λ are presented in Table 1. As can be seen, the gross margin maximisation is an important objective of all six farmers. However, in all cases, the utility function consists of more than one objectives. Especially in the case of the semi-intensive farm the gross margin maximisation objective receives a relatively low weight. Table 1 also indicates that semi-intensive farms share a common objective with intensive farms; the production of livestock feed. This derives from the significant weight of the minimisation of the amount of purchased feed objective. Especially in the case of the semi-intensive farm this objective receives a high weight regardless of the value of λ. As previously mentioned, this objective may express the desire for vertical integration and independence. It should also be emphasised that these two farm types are characterised by high degree of intensification of the sheep farming activity.

Table1. Weights by objective and farm type

Farm type	Utility function	Max Gross margin	Min Risk	Min Family labour	Min Variable cost	Min Purchased feed
Semi-intensive farm	$0 \le \lambda < 0.25$	0.22		0.17		0.61
	$0.25 \le \lambda < 1$	0.28		0.16		0.55
	$\lambda \ge 1$	0.25		0.35		0.40
Part-time farm	$0 \le \lambda \le 0.12$	0.63		0.37		
	$0.12 < \lambda < 0.17$	0.66		0.34		
	$0.17 \le \lambda \le 0.5$	0.68	0.23	0.09		
	$\lambda > 0.5$	0.69	0.07	0.24		
Extensive farm	$0 \le \lambda < 0.1$	0.66	0.29	0.05		
	$0.1 \le \lambda < 0.3$	0.66		0.05	0.29	
	$0.3 \le \lambda < 1.3$	0.69	0.31			
	$1.3 \le \lambda \le 2$	0.62		0.08	0.30	
	$\lambda > 2$	0.62	0.30	0.08		
Crop-sheep farm	$0 \le \lambda < 1.45$	0.44	0.56			
	$\lambda \ge 1.45$	0.58	0.42			
Intensive Farm	$0 \le \lambda \le 0.04$	0.55			0.45	
	$0.04 < \lambda < 8.54$	0.54				0.46
	$\lambda \ge 8.54$	0.48				0.52
Mixed livestock farm	$0 \le \lambda < 0.21$	0.52	0.48			
	$0.21 \le \lambda < 0.39$	0.47				0.53
	$\lambda \ge 0.39$	0.47	0.53			

The three more extensive farm types, in terms of the sheep production system, namely extensive, part-time, mixed livestock farms, emphasise on the maximisation of gross margin. However, an important attribute in the utility function of farmers that belong in one of these farm types is the minimisation of risk. This objective is also important in the case of the crop-sheep farm, for which only two sets of weights can be approximated (Table 1). Finally, the part-time farmer places an important weight on the minimisation of family labour, which can be explained by the presence of other off-farm activities.

The next step of the analysis is to use the estimated weights in expression (7) to form the utility function of each farmer, for various levels of λ. The utility function is then optimised subject to the constraint set. The values of the objectives predicted by the traditional gross margin maximisation model and those of the multicriteria model are then compared with the observed values. The sum of the deviations is estimated and used to assess the relative fit index (André & Riesgo, 2007). A relative fit index smaller than one indicates that the multicriteria model represents the actual operation of the farms more accurately than the traditional model. However, in order to decide on the ability of the multicriteria model to reproduce farmers' behaviour, the decision variable space is examined as well.

The results of the multicriteria and the traditional model for each farm are summarised in Tables 2-7. The multicriteria model results are presented for large values of λ (additive form of the utility function) and for λ=0 (Tchebycheff utility function). For the intermediate values of λ, the utility functions were also formed and optimised. Tables 2-7, however, present only the predicted values from the set of weights that best approximates the actual behaviour of the farmer.

In the objective space, the estimated utility functions yield better results compared to the traditional model, regardless of their form, since the relative fit index is always smaller than one (Tables 2-7). This means that the multicriteria model can represent the behavior of farmers more accurately than the gross margin maximisation model.

Specifically, in the case of the semi-intensive farm all three estimated utility functions yield better results than the traditional model (Table 2). The smallest relative fit index corresponds to the Tchebycheff function (λ=0). However all the estimated forms of the utility function have a relative fit index smaller than one, which proves the superiority of the multicriteria model. The variable space verifies the Tchebycheff form of the utility function, since the relative fit index is 0.03.

Table 2. Values of the objectives and the decision variables for the semi-intensive farm

Objective space					
	Max gross margin	λ=∞	λ=0	λ=0.3	Observed values
Gross margin (Euros)	19,497	13,648	13,648	13,648	14,418
Risk (MOTAD)	5,239	4,257	10,310	3,929	10,052
Family labour (Hours)	2,383	395	1,856	1,015	1,398
Variable cost (Euros)	15,480	14,771	12,201	12,585	12,133
Purchased feed (Mj)	79,154	2,714	27,872	0	24,600
Total deviation	4.03	2.45	0.56	1.97	
Relative fit		**0.61**	**0.14**	**0.49**	
Variable space					
Number of ewes	160	130	80	120	80
Alfalfa purchased (kg)	19,306	662	6,797	0	6,000
Maize for consumption (kg)	179,254	128,959	24,249	76,046	20,000
Barley for consumption (kg)	25,813	21,937	10,204	19,273	9,450
Wheat for consumption (kg)	0	39,123	47,447	72,205	46,000
Crops for sale (stremmas)	0	0	47	0	51
Total deviation	14.91	9.43	0.55	6.91	
Relative fit		**0.63**	**0.03**	**0.46**	

Source: Author estimations

Table 3 summarises the results for the part-time farm. Similar to the previous case, all three estimated utility functions have an increased ability to reproduce the behaviour of the farmer, compared to the traditional model. The relative fit index is smaller than one, not only in the objective space but also in the variable space. For λ= 0.5, however, the predictive ability of the model increases significantly.

Table 3. Values of the objectives and the decision variables for the part-time farm

Objective space					
	Max gross margin	λ=∞	λ=0	λ=0.5	Observed values
Gross margin (Euros)	3,530	3,101	3,151	3,400	2,860
Risk (MOTAD)	1,626	1,643	1,224	1,351	1,318
Family labour (Hours)	1,443	1,244	1,094	1,180	1,169
Variable cost (Euros)	6,280	5,759	4,225	4,764	5,013
Purchased feed (Mj)	142,841	131,844	95,455	108,070	108,120
Total deviation	1.28	0.76	0.51	0.30	
Relative fit		**0.59**	**0.40**	**0.24**	
Variable space					
Number of ewes	60	50	45	50	49
Alfalfa purchased (kg)	23,719	19,991	13,196	17,941	18,000
Barley purchased (kg)	291	481	316	190	1,200
Maize purchased (kg)	5,164	5,503	4,636	3,936	3,000
Total deviation	2.02	1.56	1.63	1,17	
Relative fit		**0.77**	**0.81**	**0.58**	

Source: Author estimations

As far as the extensive farm is concerned, the analysis indicates that the utility function of the farmer has the Tchebycheff form (Table 4). Although in the objective space the separable and additive form also seems to predict the behaviour of the farmer, this is not verified in the variable space.

Table 4. Values of the objectives and the decision variables for the extensive farm

Objective space					
	Max gross margin	λ=∞	λ=0	λ=0.2	Observed values
Gross margin (Euros)	17,167	15,786	14,861	16,423	14,010
Risk (MOTAD)	4,417	3,413	4,016	3,333	3,385
Family labour (Hours)	3,554	2,792	3,251	2,734	2,781
Variable cost (Euros)	15,982	9,827	15,283	8,582	12,352
Purchased feed (Mj)	235,499	71,207	222,187	35,804	176,400
Total deviation	1.44	0.93	0.91	1.31	
Relative fit		**0.65**	**0.63**	**0.91**	
Variable space					
Number of ewes	220	170	200	166	170
Alfalfa for consumption (kg)	26,921	19,692	27,656	17,451	30,000
Maize for consumption (kg)	11,771	18,277	11,109	20,294	9,000
Maize purchased (kg)	28,836	8,477	26,451	4,262	21,000
Total deviation	1.04	1.97	0.75	2.49	
Relative fit		**1.89**	**0.72**	**2.40**	

Source: Author estimations

The results of the crop-sheep farm indicate that the multicriteria model yields better results than the traditional one when λ=0 (Table 5). This can be observed in the variable space, where the relative fit index is smaller than one only when the Tchebycheff utility function is used. In this case, the multicriteria model can approximate not only the number of ewes but also the cash crop activities better than the traditional model.

Table 5. Values of the objectives and the decision variables for crop-sheep farm

Objective space				
	Max gross margin	λ=∞	λ=0	Observed values
Gross margin (Euros)	60,451	56,758	56,685	54,162
Risk (MOTAD)	51,202	12,080	26,535	26,162
Family labour (Hours)	2,334	2,431	2,171	2,091
Variable cost (Euros)	23,835	31,969	26,648	27,084
Purchased feed (Mj)	0	0	0	0
Total deviation*	1.31	0.93	0.12	
Relative fit*		**0.71**	**0.09**	
Variable space				
Number of ewes	240	280	203	160
Alfalfa for consumption (kg)	97,329	130,340	104,555	61,250
Maize for consumption (kg)	97,329	130,340	104,555	64,000
Maize for sale (stremmas)	0	69	51	107
Alfalfa for sale (stremmas)	110	0	50	46
Total deviation	4.03	4.27	2.24	
Relative fit		**1.06**	**0.56**	

Source: Author estimations

**the amount of purchased feed is not included, since the relative deviation cannot be defined (division with zero)*

In the case of the objective space of the intensive farm, results indicate that the multicriteria model approximates the management practices of the farmer better than the traditional model (Table 6), through all values of λ, especially when it ranges from 0.04 to 8.54 (see also Table 1). However, if the variable space is examined the relative fit index is smaller when the value of λ is very large, because in that case livestock feeding is better approximated. In this case however, the predicted number of ewes is smaller than the observed one, which leads to an underestimation of the amount of purchased feed. Therefore, we consider the multicriteria model to be more reliable when small values of λ are used (e.g. λ=0.9).

Table 6. Values of the objectives and the decision variables for the intensive farm

Objective space					
	Max gross margin	λ=∞	λ=0	λ=0.1	Observed values
Gross margin (Euros)	56,163	41,021	48,496	48,833	52,831
Risk (MOTAD)	12,244	8,679	10,436	10,529	10,375
Family labour (Hours)	2,497	1,807	2,153	2,168	2,043
Variable cost (Euros)	30,525	20,445	25,423	25,742	23,481
Purchased feed (Mj)	502,168	261,212	394,607	384,801	365,125
Total deviation	1.14	0.92	0.31	0.3	
Relative fit		**0.80**	**0.27**	**0.26**	
Variable space					
Number of ewes	282	200	240	243	240
Alfalfa produced for consumption (kg)	0	25,628	0	14,753	37,500
Maize produced for consumption (kg)	54,975	36,205	55,000	44,181	27,500
Concentrates purchased for consumption (kg)	0	0	0	0	35,000
Alfalfa purchased for consumption (kg)	122,481	63,710	96,246	93,854	20,000
Total deviation	8.30	3.99	6.82	5.92	
Relative fit		**0.48**	**0.82**	**0.71**	

Source: Author estimations

Finally, Table 7 contains the results of the mixed-livestock farm. Again, the multicriteria model yields better results, compared to the traditional model, especially when λ=0. Although, all forms of the utility function can reproduce the feeding practices of the farmer, to almost the same extent, the livestock demography is better approximated when extreme values of λ are used. The traditional model considerably overestimates the number of goats and underestimates the number of ewes.

Table 7. Values of the objectives and the decision variables for the mixed-livestock farm

Objective space					
	Max gross margin	λ=∞	λ=0	λ=0.3	Observed values
Gross margin (Euros)	15,443	12,825	13,450	12,808	12,028
Risk (MOTAD)	5,129	3,292	3,679	4,077	3,378
Family labour (Hours)	2,389	1,791	1,948	1,818	2,198
Variable cost (Euros)	18,448	10,911	12,728	13,445	14,191
Purchased feed (Mj)	362,216	192,343	234,099	249,129	227,750
Total deviation	1.77	0.68	0.45	0.59	
Relative fit		**0.37**	**0.25**	**0.33**	
Variable space					
Number of ewes	20	60	53	0	80
Number of goats	220	100	124	189	100
Oat produced for consumption (kg)	8000	8000	8000	8000	8000
Purchased maize (kg)	24,223	12,262	14,632	16,566	16,000
Purchased Forage (kg)	35,803	20,261	25,147	26,400	22,500
Total deviation	3.06	0.58	0.78	2.10	
Relative fit		**0.19**	**0.25**	**0.69**	

Source: Author estimations

Concluding remarks

In this study an attempt is made to elicit the utility function of sheep farmers' and to form a multicriteria model that can be used to analyse their behavior. The elicitation of the utility function is undertaken using a well known, non-interactive methodology, according to which, the weights attached to the objectives are estimated using their observed values. To account for the heterogeneity of the sheep farming activity in continental Greece, cluster analysis was performed and six types of sheep farms were identified. The detailed farm level data from the representative farm of each type was used to build a whole-farm model, adapted to livestock.

The results of the analysis indicate that sheep farmers aim to achieve multiple goals, one of which is the maximisation of gross margin. Extensive breeding farms (part-time farms, extensive sheep farms and mixed-livestock farms) exhibit a risk averse behaviour, which could explain their focus on livestock products that are characterised by smaller price fluctuations. On the other hand, more intensive breeding farms (semi-intensive and intensive farms) prefer the benefits of vertical integration and independence. These results indicate a link between farm structures and farmers' preferences and objectives. It should be noted, however, that some aspects of farmers' behaviour, such as their attitude towards matters of animal welfare and environment, have not been taken into account in the analysis, because of the difficulty of the quantification of such concepts.

To conclude, it should be mentioned that the structure and management of sheep farms are better approximated through the use of the multicriteria model. This questions the use of the traditional model as a policy tool, since it significantly deviates from the actual behaviour of the farmers.

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