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Multiple goals in farmers' decision making: The case of sheep farming in western Greece

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Abstract

Management strategies and performance differ among farmers, as a result of different, multiple and often conflicting goals. Many approaches to building farm level models that incorporate multiple goals have been developed over the years, most of which share a common weakness. The determination of the goals to be used as attributes in the utility function is the result of a highly interactive process with the individual farmer, often difficult to implement. In this study, we use a non-interactive methodology, described in recent literature, to elicit the utility function of selected sheep farmers in western Greece, since farmers often appear reluctant to answer straightforward questions about their goals and preferences. The results indicate that sheep farmers aim at the achievement of multiple goals, and that the maximization of gross margin is an important attribute in the utility function of mainly larger farms with a commercial orientation. The minimization of purchased forage, family labor and cost of hired labor are also important goals, especially for small and less commercial family farms. The multi objective farm level model built reproduces the Greek sheep farmers' behavior more accurately and can replace the single objective model in decision making or agricultural planning problems.

Key words: Sheep farming, mixed integer programming, multiple goals, non-interactive elicitation

JEL codes: C61, D21, Q12

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Introduction

Sheep farming is an important agricultural activity in Greece, where almost 1% of the world population of sheep is located (Zygoyiannis, 2006). The activity contributes highly in the country's gross agricultural production value and in regional development especially in isolated and less favored areas (H.M.R.D.F.[1], 2007). The majority of Greek sheep farms produce both meat and milk, but the main element of their farm income is the gross revenue of milk (Hadjigeorgiou, 1999; Zioganas *et al.*, 2001; Kitsopanidis, 2006).

There are mainly four types of ruminant production systems identified in Greece, the semi intensive, the sedentary extensive, the transhumant and the small intensive system, but over the last two decades only the first two subsist. These systems have different technical and economic characteristics and achieve different levels of productivity (Rancourt et al., 2006). However, the majority of sheep farms are small, extensive, family farms, characterized by a high degree of diversification in terms of herd size, invested capital, productivity and orientation (H.M.R.D.F., 2007). In the case of Greece, sheep farming is often a side activity or only part of the production plan of the farm. According to the N.S.S.G.[2] (2000) almost 63% of the Greek sheep farms have a number of sheep less than 50. Almost 85% of the Greek sheep farms are extensive and have low invested capital (H.M.R.D.F., 2007). On the other hand, more intensive and modern farms have appeared recently, especially in lowland areas. Thus, there are various types of sheep farms in Greece, placed between small subsistence farms and large, sheep oriented, commercial farms.

This high degree of diversification between sheep farms is linked to different management strategies and insinuates different objectives amongst farmers. The assumption that profit maximization is the common and only goal of farmers appears to be in conflict with the observed structure of sheep farming, described above. The

[1] Hellenic Ministry of Rural Development and Food
[2] National Statistical Service of Greece

development of different management strategies is the result of farmers' individual preferences and combination of goals. Many studies focus on the relationship between individual goals and the development of management styles and strategies (Harman et al., 1972; Cary & Holmes, 1982; Fearwheather & Keating, 1994; Costa & Rehman, 1999; Solano et al., 2001; Vandermersch & Mathijs, 2002; Bergevoet et al., 2004).

In this sense, farm level models used in agricultural planning, which ignore multiple goals, and assume only profit maximization, are less effective and often misleading (Arriaza & Gómez-Limón, 2003). Nevertheless, single objective linear programming models are commonly used to capture livestock farmers' decision making process. (Biswas et al., 1984; Conway & Killen, 1987; Alford et al.,2004; Veysset et al., 2005; Crosson et al., 2006).

On the other hand, models that incorporate multiple goals can assist policy makers in developing more efficient and targeted policy measures and adjust the existing policy regime accordingly. The purpose of this study is to build a multi-objective farm level model that could replace traditional single objective models used in agricultural planning. In order to build a farm level model that can incorporate multiple goals, a highly interactive process with the individual farmer must be implemented. This is often a time consuming effort and can lead to ambiguous results (Patrick & Blake, 1980; Sumpsi et al, 1996).

For this reason the elicitation of the multi-dimensional utility function is attempted using a non-interactive methodology proposed by Sumpsi et al. (1996) and further extended by Amador et al., (1998). The use of this methodology allows researchers to study multiple goals of farmers, without encountering the problems related to interaction techniques. In the case of sheep farmers in Greece such a methodology can be proven a very useful tool for researchers, provided the results it yields can explain farmers' behavior adequately.

In the following section the multi-criteria methodology, used in this analysis, is described. Next the case study and the model specification are presented. The last two sections of this study contain the results of the analysis and some concluding remarks.

Methodology

Since the existence of multiple goals in agriculture has been recognized, many approaches to building decision making models based on this viewpoint have been developed. Multi criteria approaches, mainly goal programming and multi objective programming are most common in agricultural studies (McGregor & Dent, 1993; Piech & Rehman, 1993; Siskos et al., 1994; Berbel & Rodriguez-Ocaña, 1998). In these approaches, the goals incorporated in the model and the weights attached to them are either predefined by the researcher, or elicited through an interactive process with the farmer (Dyer, 1972; Barnett et al., 1982; Rehman & Romero; 1993). Although the second approach is theoretically sounder, in practice, this high degree of interaction with the farmer comes with many difficulties. Farmers often find it difficult to define their goals and articulate them (Patrick & Blake, 1980). Educational background may make this interaction process or the self reporting of goals a less suitable approach. Furthermore it has been noted that farmers feel uncomfortable when asked about their goals. The need to employ a different method to determine farmers' objectives in multi criteria studies is rather transparent and imperative.

In this study, a well-known non-interactive methodology to elicit the utility function of each farmer is applied (Sumpsi et al., 1996).This methodology allows multiple goals to be incorporated in the farm level model and requires no interaction with the decision maker. It is based on the determination of the objectives and their relative importance according to the farmer's actual and observed behavior. In order to describe the methodology used in the analysis we assume:

x = vector of decision variables (see Appendix A)

F = feasible set (see Appendix A)

$f_i(x)$ = mathematical expression of the i-th objective (see Model Specification)

w_i = weight measuring relative importance attached to the i-th objective

f^*_i = ideal or anchor value achieved by the i-th objective

f_{*i} = anti-ideal or nadir value achieved by the i-th objective

f_i = observed value achieved by the i-th objective

f_{ij} = value achieved by the i-th objective when the j-th objective is optimized

n_i = negative deviation (underachievement of 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)

The first step of the methodology consists of defining a set of tentative objectives $f_{1(x)}, \ldots, f_{i(x)}, \ldots, f_{q(x)}$. The definition of the set of goals can be achieved through preliminary interviews of farmers. The second step consists of the determination of the pay off matrix by optimizing each objective separately, over the feasible set and calculating the value of each objective at each of the optimal solutions (Sumpsi et al., 1996). Thus, the first entry of the pay-off matrix is obtained by:

$$Max f_1(x), \text{subject to } x \in F \quad (1)$$

since $f_1^* = f_{11}$. The other entries of the first column of the matrix are obtained by substituting the optimum vector of the decision variables in the rest *q-1* objectives. We can obtain the rest of the entries of the matrix accordingly. In general, the entry fij will be acquired by maximizing $f_j(x)$ subject to $x \in F$ and substituting the corresponding optimum vector x^* in the objective function $f_i(x)$.

The elements of the pay off matrix and the observed (actual) values for each objective are then used to build the following system of *q* equations. This system of equations is used to determine the weights attached to each objective:

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

$$\sum_{j=1}^{q} w_j = 1 \quad (2)$$

If the above system of equations has a non negative solution then this solution represents the set of weights to be attached to the objectives so that the actual behavior of the farmer can be reproduced ($f_1, f_2, \ldots, f_q$). Usually the above system of equations has no exact solution and thus the best solution – the of set of weights $w_1, w_2, \ldots, w_q$ that reproduce the preferences of the farmer- has to be alternatively approximated. For this reason the L_1 criterion for minimizing the corresponding deviations is used (Sumpsi et al., 1996; Amador et al., 1998).

The L_1 criterion aims at the minimization of the sum of positive and negative deviational variables. The weighted goal programming technique can be used to solve this problem (Charnes et al., 1955; Appa & Smith, 1973; Sumpsi et al, 1996). The formulation of the weighted goal programming technique is shown below:

$$Min \sum_{i=1}^{q} \frac{(n_i + p_i)}{f_i}$$

subject to:

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

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

The L_1 criterion corresponds to a separable and additive utility function (Sumpsi et al., 1996). The form of the utility function is shown below:

$$u = \sum_{i=1}^{q} \frac{w_i}{k_i} f_i(x) \tag{4}$$

k_i is a normalizing factor (for example: $k_i = f_i^* - f_{i*}$). The use of a normalizing factor is essential in cases where the goals used in the analysis are measured in different units. If the weights estimated through the goal programming technique are used in the utility function without having been normalized then the goals with high absolute values will erroneously appear to have a larger weight. It is therefore important to use the normalizing factor when using the weights to form the utility function (Rehman & Romero, 1993; Sumpsi et al., 1996; Tamiz et al., 1998).

It should be mentioned that the entire series of L metrics can be used to minimize the corresponding deviations. The L_∞ criterion is most commonly used, partly because it can be managed through an LP specification, according to which the maximum deviation D is minimized (Appa & Smith, 1973). The L_∞ criterion corresponds to a Tchebycheff utility function that implies a complementary relationship between objectives (Amador et al., 1998). Nevertheless, in this first attempt to explore the behaviour of sheep farmers in Greece we assume the separable and additive utility function (equation 4), often used in agricultural studies (Sumpsi et al., 1996; Gómez-Limón et al., 2003).

The next step is to validate the model, that is to check whether the utility function estimated can accurately reproduce farmers' behavior. For this reason the utility function (4) is maximized subject to the constraint set (see Appendix A) and the results of the maximization are compared to the actual values of the q goals. Namely, the following mathematical programming problem is formulated and solved:

$$Max \sum_{i=1}^{q} \frac{w_i}{k_i} f_i(x)$$

Subject to:

$$f_i(x) + n_i - p_i = f_i \qquad i = 1,2...,q \qquad (5)$$

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

If the preference function gives results close to the actual values for each goal then it is considered the utility function that is consistent with the preferences of the farmer. It should be noted that if the above utility function cannot reproduce farmer's behavior, other forms of the utility function should be examined (Sumpsi et al., 1996; Amador et al., 1998). The utility function has to represent the actual situation accurately, not only as far as the alternative objectives are concerned, but also against decision variables.

Case study

The development of a whole farm model requires detailed farm level data. In this study we focus on six sheep farms selected in the prefecture of Etoloakarnania, which is located in Western Greece. The area of Etoloakarnania produces over 6% of the total sheep milk and lamp meat in Greece (N.S.S.G., 2006). In this prefecture, sheep farming is a common and traditional activity, since almost 9% of the total number of Greek sheep farms, is located in this area (N.S.S.G., 2000).

Selected farms have different characteristics like herd size, production orientation, specialization, breeding system, amount of farm produced forage and concentrates and labor requirements, so that the desired degree of diversification can be achieved. This way, the multiple goals and behavior of farmers that follow different management strategies and own different types of farms, can be studied. Previous studies indicate that the goals of farmers can differ between large and smaller farms (Gasson, 1973; Wallace & Moss, 2002), while others detect no difference between farms of different sizes (Ilbery, 1983). In the case of sheep farming in Greece, where 63% of the farms have a small livestock, it is necessary to study these farms along with the larger farms and stress any differences between them.

For the above reasons, the first two farms that were selected for the analysis are large, commercial and extensive-breeding farms (farms A and B). The difference between them is that farm A produces part of the forage and concentrates it uses, while farm B purchases all and concentrates used. Farm C is more intensive and uses less pastureland, while it produces alfalfa and corn not only to cover the needs of the livestock activity but also for sale. The last three (D, E and F) farms are small scale farms, representing only a part time activity for their owners, which is a common case in the area under study. They differ in their production activities and other technical characteristics. Farm D produces the alfalfa and corn it uses, farms E produces only alfalfa and farm F produces no forage. All small farms tend to sell lambs at higher weight (rearing) than the large farms who sell their lambs after weaning. The gathered data refers to the year 2004-2005 (annual data) that was a typical year for Greek agriculture. It should also be noted that the data refer to the previous CAP regime.

Model specification

The implementation of multi-criteria analysis supposes the construction of a linear programming model that can reflect the characteristics and constraints of the farm accurately. Therefore, the model consists of 144 decision variables and 95 constraints that cover both animal and crop activities of the farm. There are three sets of decision variables included in the model. The first set involves the production of fodder and concentrates crops (mainly alfalfa and corn), the use of pastureland (area of different kinds of pastureland engaged by the farm) and the monthly consumption of the produced or the purchased forage and concentrates. The next set involves monthly family and hired labor engaged in crop and animal activities. The last set of decision variables involves the animal activities of the farm and the area engaged in the production of crops for sale (not consumption in the farm). It should be noted that there are four animal activities incorporated in the model, defined by whether the lambs are sold after weaning or three months after birth (rearing) and by whether the ewes are premium eligible or not (see Appendix A).

The constraint matrix includes the land constraints (total own land, irrigated land, available pastureland e.t.c.), the monthly distribution of produced fodder and concentrates, monthly nutrient requirements (dry matter, NEL[3], digestible nitrogen), monthly labor requirements of all activities and policy constraints (number of premium eligible ewes). It should be mentioned that other livestock linear programming models include similar decision variables and constraints (Conway & Killen, 1987; Alford et al.,2004; Crosson et al., 2006). For the estimation of the nutrient requirements of the flock the methodology described by Zervas et al. (2000) has been used. The mathematical expression of the constraint matrix and the decision variables are presented in Appendix A.

What should also be mentioned is that the model used in this study is in fact a Mixed Integer Programming Model, since some variables are constrained to receive only integer numbers. These variables refer to the number of ewes. The Mixed Integer Programming Models are commonly used, when livestock, crop-livestock and aquaculture farms are studied (Engle, 1987; Shaftel & Wilson, 1990).

Initial set of goals

In this analysis we have used five goals. The first goal is the maximization of the total gross margin, used in most decision making models (Piech & Rehman, 1993; Berbel & Rodriguez-Ocaña, 1998; Wallace and Moss, 2002). We have also included the minimization of variable cost as an important goal of sheep farmers. Greek farmers often place more value on keeping their expenses (mainly variable cost) low, than on making maximum profit. This goal has also been identified and studied in the past

[3] Net Energy of Lactation (Mj)

(Piech & Rehman, 1993). The third goal involves the minimization of family labour. This goal is strongly linked to the fact that the farm is a production and a consumption unit at the same time. This is the main reason why conflicting goals often appear as important attributes in farmers' utility function. The minimization of labour is strongly linked to the increase of farmers' leisure time. The importance of this goal is stressed in a number of studies of farmers' goals (Barnett et al., 1992; Wallace, 1998).

The fourth goal is linked mainly with the increasing concern about the quality and hygiene of forage and other concentrates. Farmers, especially those that consume part of their products, or aim to produce and promote quality products; prefer to feed their livestock with forage and concentrates produced in the farm. This is mainly the strategy smaller farms are most likely to follow, because production is limited and can be promoted directly to consumers. The last goal is the minimization of the cost of foreign labour (Piech & Rehman, 1993; Berbel & Rodriguez-Ocaña, 1998). This is a major concern of larger farms that attempt to utilise family labour to increase farm income. But this is not the only reason, since hired labour is not always abundant. Consequently, farmers may need to restrict the size of the livestock so as to depend only on family labour. The five goals used in this analysis and their mathematical expressions are given below (also see Appendix A for the indices, parameters and decision variables used):

1. Maximization of gross margin (measured in euros)

$$f(1) = Max[\sum_{ti} gr\_marc_{ti,sales} \cdot crop_{ti,sales} + \sum_{r}\sum_{a} gr\_mara_{a,r} \cdot anim_{a,r} - \sum_{g} rqwc_{t,g} \cdot gland_{g} - \sum_{t}\sum_{fi} rqwc_{fi,t} \cdot feed_{fi,t} - \sum_{t}\sum_{fs} rqwc_{fs,t} \cdot feed_{fs,t} - \sum_{r}\sum_{a} rqwc_{a,t} \cdot anim_{a,r} - \sum_{ti} rqwc_{ti} \cdot crop_{ti,"con,sales"}] \quad (6)$$

2. Minimization of the variable cost (measured in euros)

$$f(2) = Min[\sum_{g} rqwc_{t,g} \cdot gland_{g} + \sum_{t}\sum_{fi} rqwc_{fi,t} \cdot feed_{fi,t} + \sum_{t}\sum_{fs} rqwc_{fs,t} \cdot feed_{fs,t} + \sum_{r}\sum_{a} rqwc_{a,t} \cdot anim_{a,r} + \sum_{ti} rqwc_{ti} \cdot crop_{ti,"con,sales"}] \quad (7)$$

3. Minimization of the family labour (measured in hours)

$$f(3) = Min\sum_{l}\sum_{t} lab_{l,own,t} \quad (8)$$

4. Minimization of the amount purchased forage and concentrates[4]

$$f(4) = Min \sum_{fs} \sum_{t} y_{fs,energy} feed_{fs,t} \tag{9}$$

5. Minimization of hired labor (measured in hours)

$$f(5) = Min \sum_{l} \sum_{t} lab_{l,hire,t} \tag{10}$$

Results of the analysis

The first step of the analysis is to obtain the Pay-off matrix for each of the six farms, as described above. The entries of the Pay-off matrix together with the observed values for each objective are used to build the system of equations (11) that will provide the weights of each objective:

$$\begin{bmatrix} f_{11} = f_1^* \cdots f_{12} \cdots f_{1i} \cdots f_{1q} \\ f_{i1} \cdots f_{i2} \cdots f_{ii} = f_i^* \cdots f_{iq} \\ f_{q1} \cdots f_{q2} \cdots f_{qi} \cdots f_{qq} = f_q^* \end{bmatrix} \begin{bmatrix} w_1 \\ w_i \\ w_q \end{bmatrix} = \begin{bmatrix} f_1 \\ f_i \\ f_q \end{bmatrix} \tag{11}$$

The estimated weights (Table 1) reveal that gross margin maximization is a significant attribute in the utility function of larger farms (A, B and C). Specifically, the maximization of gross margin appears to be the only objective of farm B. For Farm A, the maximization of the gross margin is equally important with the minimization of hired labor. It should be noted that the farm actually has high labor requirements, especially for grazing. For Farm C, which is also comparatively large, the main attribute of the utility function is also the maximization of the gross margin. Another important attribute in the utility function of Farm C is the minimization of purchased forage and concentrates, since one of the farm's main activities is the production of alfalfa and corn, not only for consumption but also for sale.

The other three farms (D, E and F) are part time, family enterprises. This may explain the fact that two of them (Farm D and F) aim not only at gross margin maximization

[4] The variable $feed_{fi,t}$ refers to kilograms of purchased fodder and concentrates of various types, with different nutritional and energy value. Therefore minimising the sum of all purchased fodder and concentrates would lead to the substitution of low nutritional value crops (used in larger amount) with high nutritional value crops (used in smaller amount). To avoid this mistake we use the parameter $y_{fs,energy}$ as a normalizing factor. This means that the 4th goal expresses the "purchased energy" measured in Mj.

but also at minimization of family labor. Pluriactive farmers' probably need to save on labor inputs so that they can invest time and effort in their off – farm activities. Farm D also aims at minimizing the purchased forage and concentrates it uses. It should be noted that the family consumes part of the meat and milk it produces, while it sells the rest directly to consumers. Farm E is the only farm under study for which the maximization of the gross margin does not appear in the utility function. The farmer aims at keeping his variable cost at a manageable level and at using his own forage. The above findings indicate that the maximization of gross margin has a higher weight in the utility function of larger farms, while the smaller farms develop diversified strategies.

The estimated weights of each objective were used to build the utility function of each farmer. This utility function is then maximized subject to the model constraints to approximate farmers' behavior. First, the predicted values of all objectives, according to the traditional profit maximization objective function and according to the estimated utility function, are compared (Amador et al, 1998). But in order to decide on the ability of the multicriteria model to reproduce farmers' behavior, the decision variable space has to be taken into account as well. Tables 2-7 summarize the predicted values of the objectives and the decision variables for all farms. The observed values are included in the tables; while the last two columns contain the absolute deviations of the predicted values from the observed values, in the case of gross margin maximization and the maximization of the estimated utility function. The total deviation from the observed behavior is also presented, while the last row contains the ratio of the deviations (total deviation in the case of the multicriteria model/total deviation in the case of the traditional model) (André & Riesgo, 2007).

The estimated utility function yields better results in all cases, except for Farm B that has a single-objective utility function. This means that the multicriteria model can represent the behavior of farmers more accurately than the traditional gross margin maximization model. Specifically, in the case of the first farm (A) the suitability of the multi criteria model compared to the traditional model is transparent, especially when examining the values of objectives (Table 2). The traditional model fails to simulate the actual behavior especially in the case of the purchased forage and cost of hired labor. As far as the basic decision variables are concerned, the number of ewes is better simulated in the multicriteria model, although both models approximate the animal practice that the farm actually maintains (sell lambs after weaning).

Farm B is the only farm for which the utility function is single objective (maximization of gross margin). The model reproduces the actual values of the objectives more accurately in the case of gross margin, family labor and cost of hired labor (Table 3). The actual values of the purchased forage-concentrates and variable cost are higher, due to the fact that the actual number of ewes is 20% higher. As for farm C, the multicriteria model has a slightly increased ability to reproduce farmer's behavior, compared to the traditional model (Table 4).

The quality of the multicriteria model relative to the gross margin maximization model can be easily observed in the case of the small family farms. For Farm D the total deviation and the relative fit index reveal that the approximations of the multi criteria model are better, mainly in the case of gross margin and variable cost (Table 5). The gross margin maximization model failed to represent the actual operation of the farm. For Farm E the multicriteria model appears to give excellent approximations of the observed values of both the objectives and the decision variables. The relative fit index in Tables 6 is very small; indicating that the multicriteria model outweighs the gross margin maximization model, in terms of the ability to reproduce the observed values, and that studying the behavior of farmers under the assumption of profit maximization can be misleading. The deviation of the predicted values of the single objective model is especially significant in the case of the variable cost, the purchased forage-concentrates and the number of ewes. On the other hand, the multicriteria model has an excellent performance in all cases.

Finally, as far as Farm F is concerned, the superiority of the multicriteria model compared to the traditional model is transparent in the case of purchased forage and concentrates and in the case of the variable cost (Table 7) Also, the estimation of the number of ewes is closer to the actual number than in the case of the single objective model.

It should be noted that the model verifies the practice of farmers as far rearing is concerned. Rearing is the common practice of smaller farms, while larger farms benefit mainly from milk and sell their lambs after weaning.

Concluding remarks

In this study the elicitation of the utility function of sheep farmers' and the formation of a multicriteria model that can be used to analyze their behavior is attempted. For this reason a detailed whole farm model adapted to livestock was built that incorporates decision variables and constraints for all animal and crop activities. The elicitation of the utility function is undertaken through a non interactive methodology, so that the drawbacks of the interactive methods can be limited. The weights attached to the objectives of six farmers are estimated using the actual values of the objectives and the multi attribute utility function is then used to reproduce their behavior.

The results of the analysis indicate that sheep farmers aim to achieve multiple goals, one of which is the maximization of gross margin. This objective is the most important attribute of the utility function of two out of the six farms under study. The main difference between the various farm types is the combination of objectives. This combination is rather more complex in the case of the small, family farms. The objective of gross margin maximization is an important attribute in the utility function of larger farms with a commercial orientation, but the weight assigned to this objective is small in the cases of less commercial farms. In fact, in one case the utility function does not include the maximization of gross margin. The minimization of purchased forage and concentrates, the minimization of family labor and the minimization of variable cost are significant attributes in the utility function of small scale, family farms, while the minimization of hired labor is also important in two out of six farms.

In general, the analysis indicates that the performance of the mathematical model built to reproduce the operation of a crop-livestock farm can improve through the use of multiple objectives. This is useful in many practical ways, since it can be used in farm management to develop a realistic scenario for the development of the farm but also in agricultural planning and policy, since it can replace the less accurate single objective models.

Finally it should be noted, that in this analysis we have used the additive form of the utility function, but the use and applicability of other forms of the utility function can also be investigated. This study is a first attempt to build a multicriteria model to explain the behavior of livestock farmers and further research is required. The existence of other objectives, such as minimization of risk, is another concept for future research.

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Appendix A

Mathematical expression of the constraints and decision variables of the LP model:

Indices:

ti	cultivated crops
fi	cultivated fodder and concentrates
fs	purchased fodder and concentrates
a	animal activities (A = {sheep3, sheep-3})
r	animal premiums (C= {right, nright})
m	destination of produced fodder and concentrates (M = {con, sale})
l	destination of labor (L = {crops, flock})
s	origin of labor (S = {own, hire})
t	month
g	type of pastureland (G={rent, own, com})
u	nutritional value (U={dry matter, nitrogen, energy})

Model parameters:

$Yield_{ti}$	crop yield (kg)
$y\_gz_{t,u}$	nutritional value of pastureland per month (kg)
$y_{fi,u}$	nutritional value of produced forage and concentrates (kg)

$y_{fs,u}$	nutritional value of purchased forage and concentrates (kg)
$n_{a,t,u}$	monthly feed requirements (kg)
$rclab_{ti,t}$	monthly labor requirements for crops (hr)
$ralab_{ti,t}$	monthly labor requirements for animal activities (hr)
$\text{avail}_{l,t}$	available family labor per month (hr)
own_land	available owned land (stremma[5])
rent_land	available pastureland for rent (stremma)
irr_land	irrigated land (stremma)
graz_mun	available communal pastureland (stremma)
land	total land (stremma)
num_elig	number of premium eligible ewes (number)
gr_marc_{ti}	gross margin of crops (gross revenue minus all variable cost except labor) (€)
$\text{gr\_mara}_{a,r}$	gross margin of animal activities (gross revenue minus all variable cost except labour and feed cost) (€)
rqwc_{ti}	variable cost required for crops (euro/stremma)
rqwc_{a}	variable cost required for animal activities (euro/ewe)
rqwc_{fi}	cost of produced fodder and concentrates (euro/kgr)
rqwc_{fs}	cost of purchased fodder and concentrates (euro/kgr)

Decision variables

$crop_{fi,auto}$	produced fodder and concentrates (kg)
$crop_{ti,sales}$	crops for sale (stremma)
$feed_{fs,t}$	monthly purchased fodder and concentrates (kg)
$feed_{fi,t}$	consumption of produced fodder and concentrates/month (kg)
$lab_{l,s,t}$	labor per month, destination and origin (hr)
$gland_g$	pastureland (stremma)
$anim_{a,r}$	ewe (number)

The mathematical expression of the constrain matrix is the following:

Distribution of produced crops:

$$yield_{fi} \cdot crop_{fi,con} = \sum_t feed_{fi,t} \qquad \forall fi \in \text{FI}$$

[5] 1 Stremma = 0,1 Ha

Feed requirements

$$\sum_{g} y\_gz_{t,u} \cdot gland_{g} + \sum_{fi} y_{fi,u} \cdot feed_{fi,t} + \sum_{fs} y_{fs,u} \cdot feed_{fs,t} \geq \sum_{r} \sum_{a} n_{a,t,u} \cdot anim_{a,r}$$

$\forall\ t \in \mathrm{T},\ \forall\ u \in \mathrm{U}$

Labor requirements for crops:

$$\sum_{ti} rclab_{ti,t} \left(crop_{ti,sales} + crop_{fi,con}\right) \leq \sum_{s} lab_{crops,s,t} \qquad \forall\ t \in \mathrm{T}$$

Available family labor:

$$lab_{l,own,t} \leq avail_{l,t} \qquad \forall\ t \in \mathrm{T}$$

Labor requirements of the flock:

$$\sum_{a} ralab_{a,t} anim_{a,r} \leq \sum_{s} lab_{l,s,t} \qquad \forall\ t \in \mathrm{T}$$

Available irrigated land:

$$\sum_{ti} \left(crop_{ti,sales} + crop_{fi,con}\right) \leq irr\_land$$

Available own land:

$$\sum_{ti} \left(crop_{ti,sales} + crop_{fi,con}\right) + gland_{own} \leq land$$

Communal pasture land[6]

$$gland_{mun} \leq graz\_mun$$

Available land for rental:

$$gland_{rent} \leq rent\_land$$

Number of ewe rights:

$$\sum_{a} anim_{a,"elig"} \leq num\_elig$$

[6] Pastureland, property of the municipality, distributed among livestock farms according to their ewe rights. In exchange, livestock farms pay a small fee to the municipality.

Appendix B

Table 1. Estimated weights of the objectives of the farms

	Max gross margin	Min variable cost	Min family labour	Min purchased forage-concentrates	Min cost of hired labour
Farm A	48%				52%
Farm B	100%				
Farm C	66%			32%	
Farm D	30%		48%		22%
Farm E		33%		67%	
Farm F	23%		77%		

Table 2. Observed and predicted values of the objectives and decision variables for Farm A

	Max gross margin	Estimated utility function	Observed values	Abs. deviation **(Estimated function)**	Abs. deviation **(gross margin)**
Values of objectives					
Gross margin (€)	41616	39642	36986	0.07	0.13
Variable cost (€)	54013	27830	31680	0.12	0.70
Family labour (h)	4843	4216	4843	0.13	0.00
Purchased feed (MJ)	672596	241861	324844	0.26	1.07
Hired labour (€)	16935	7328	7958	0.08	1.13
Total deviation				**0.66**	**3.03**
Relative fit					**0.22**
Decision variables					
3-month ewes	0	0	0		
Weaning ewes	343	211	262	0.19	0.31
Alfalfa produced*	73	65	40	0.63	0.83
Corn produced*	7	15	40	0.63	0.83
Total pastureland*	800	800	800	0.00	0.00
Other crops*	5	5	5	0.00	0.00
Total deviation				**1.44**	**1.96**
Relative fit					**0.74**

*Stremmas

Table 3. Predicted and observed values of the objectives for Farm B*

	Max gross margin	Estimated utility function	Observed values	Abs. deviation
Gross margin (€)	19087	19087	18.339	0,04
Variable cost (€)	15343	15343	22.017	0.30
Family labour (h)	4255	4255	4.724	0.10
Purchased feed (MJ)	157226	157226	217.090	0.28
Hired labour (€)	7370	7370	7.388	0.00
Total deviation				**0.72**

*Since both models coincide, the values of the decision variables are identical

Table 4. Predicted and observed values of the objectives and the decision variables for Farm C

	Max gross margin	Estimated utility function	Observed values	Abs. deviation **(Estimated function)**	Abs. deviation **(gross margin)**
Values of objectives					
Gross margin (€)	22269	22165	20798	0.07	0.07
Variable cost (€)	7913	7687	8153	0.06	0.03
Family labour (h)	2755	2715	2274	0.19	0.21
Purchased feed (MJ)	0	0	0	0.00	0.00
Hired labour (€)	443	416	350	0.19	0.27
Total deviation				**0.51**	**0.58**
Relative fit					**0.87**
Decision variables					
Ewes	157	134	80	0.67	0.96
Alfalfa produced*	38	33	35	0.06	0.09
Corn produced*	28	33	31	0.07	0.10
Total pastureland*	15	15	15	0.00	0.00
Other crops*	9	9	9		
Total deviation				**0.80**	**1.15**
Relative fit					**0.69**

*Stremmas

Table 5. Predicted and observed values of the objectives and the decision variables for Farm D

	Max gross margin	Estimated utility function	Observed values	Abs. deviation **(Estimated function)**	Abs. deviation **(gross margin)**
Values of objectives					
Gross margin (€)	8890	5894	4386	0.34	1.03
Variable cost (€)	7444	3418	3521	0.03	1.11
Family labour (h)	1547	474	1414	0.66	0.09
Purchased feed (MJ)	158070	37353	0	-	-
Hired labour (€)	0	0	201	1.00	1.00
Total deviation				**2.04**	**3.23**
Relative fit					**0.63**
Decision variables					
3-month ewes	61	15	15	0.00	3.07
Weaning ewes	0	0	0	0.00	0.00
Alfalfa produced*	25	28	17	0.65	0.50
Corn produced*	0	0	4	1.00	1.00
Total pastureland*	15	15	15	0.00	0.00
Other crops*	3	0	7	1.00	0.63
Total deviation				**2.65**	**5.20**
Relative fit					**0.51**

*Stremmas

Table 6. Predicted and observed values of the objectives and the decision variables for Farm E.

	Max gross margin	Estimated utility function	Observed values	Abs. deviation **(Estimated function)**	Abs. deviation **(gross margin)**
Values of objectives					
Gross margin (€)	8010	4483	6404	0.30	0.25
Variable cost (€)	10197	2824	2659	0.06	2.83
Family labour (h)	1584	1042	1285	0.19	0.23
Purchased feed (MJ)	215120	16617	16800	0.01	11.80
Hired labour (€)	934	493	376	0.31	1.48
Total deviation				**0.87**	**16.61**
Relative fit					**0.05**
Decision variables					
3-month ewes	78	20	20	0	2.90
Weaning ewes	0	0	0	0.00	0.00
Alfalfa produced*	18	18	18	0.00	0.00
Corn produced*	0	0	0	0.00	0.00
Total pastureland*	15	15	15	0.00	0.00
Other crops*	5	4,6	5	0.08	0.00
Total deviation				**0.08**	**2.90**
Relative fit					**0.03**

*Stremmas

Table 7. Predicted and observed values of the objectives and the decision variables for Farm F.

	Max gross margin	Estimated utility function	Observed values	Abs. deviation **(Estimated function)**	Abs. deviation **(gross margin)**
Values of objectives					
Gross margin (€)	4494	2289	3263	0.30	0.38
Variable cost (€)	5096	2055	3108	0.34	0.64
Family labour (h)	952	270	671	0.60	0.42
Purchased feed (MJ)	141594	53158	73567	0.28	0.92
Hired labour (€)	24	0	6	1.00	3.42
Total deviation				**2.51**	**5.78**
Relative fit					**0.43**
Decision variables					
3-month ewes	45	21	20	0.05	1.25
Weaning ewes	0	0	0		
Total pastureland*	23	26	23	0.13	0.00
Other crops*	3	0	3	1.00	0.00
Total deviation				**1.18**	**1.25**
Relative fit					**0.94**

*Stremmas