Multi-criteria analysis of factors use level:

The case of water for irrigation

José A. GÓMEZ-LIMÓN[a], Laura RIESGO[a] and Manuel ARRIAZA[b]

[a] Department of Agricultural Economics, E.T.S.II.AA. University of Valladolid
Avda. de Madrid, 57. 34071 Palencia. Spain. *E-mail*: limon@iaf.uva.es (J.A. Gómez-Limón).

[b] Department of Agricultural Economics, Centro de Investigación y Formación Agraria (CIFA)
Alameda del Obispo s/n, PO Box 3092, 14080 Córdoba. Spain.

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Abstract

In this paper we present a methodology to analyse input use in the agricultural sector. The novelty of the theoretical model explained is that it has been developed considering a multi-criteria environment. Thus, the optimal input use condition is determined by the assessment of "multi-attribute utility" and "multi-attribute marginal utility". We show how the approach adopted in this paper is a generalization of the single-attribute expected utility theory. The theoretical model developed is further implemented in an empirical application that studies water for irrigation use as a particular case. Results show how multi-attribute utility functions elicited for a sample of 52 irrigators explain differences on irrigation water use in relative homogenous agricultural systems, albeit exhibiting similar water partial utility functions. We conclude that these differences come from the dissimilar weights that farmers attached to each attribute in the aggregate utility function. The irrigated area considered as case study is located in North-western Spain.

JEL classification: C61, D21, Q25

Keywords: Production Theory, Input Use, MAUT, Water for Irrigation, Spain.

1. Introduction

Spanish authorities have recently introduced a new legislative framework aiming to promote demand water policies as an alternative to traditional supply water policies. This new institutional environment includes higher water pricing, complying with the European Water Framework Directive, the introduction of water markets and a new subsidy scheme in order to achieve water conservation in irrigated areas.

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* Corresponding author. Tel: +34 979 108341; Fax: +34 979 108301.

E-mail address: limon@iaf.uva.es

All these policy instruments have been designed and implemented assuming the producers' rational behaviour of profit maximization. Following this assumption, farmers use water for irrigation up to a level where the marginal product value equals the water price ($MgPV_w=P_w$). Thus, an increase of price devised by the authorities aims a left-shift of the factor production function, therefore encouraging a decrease in this input use and so a more efficient use of this factor in the agricultural sector.

Following the classical approach of input allocation, the implementation of water markets is expected to move water from lower to higher marginal productivity uses. Thus, farmers can trade their water use rights and sell them to a point where the water marginal productivity equals the water price of the market, therefore, improving water allocation efficiency.

In the same way, the Spanish agricultural policy orientated towards the modernization of the irrigation systems targets the most inefficient producers to improve water productivity and farm income. This policy has been implemented through subsidies in order to partially compensate investment costs and thus, allowing farmers to obtain a net profit for the water conservation measure achieved. The combination of this policy with the water price increase will presumably reduce the water demand for agricultural uses. For a comprehensive review of policy water instruments see for example Boggess *et al*. (1993), Carruthers y Clark (1981), FAO (1995), Merret (1997) or OECD (1998).

However, many studies have rejected the hypothesis of farmers' profit maximization behaviour, suggesting that producers seek to optimize a set of objectives apart from the former such as risk minimization, the maximization of leisure time, the minimization of working capital, etc. The implication of this is clear: the impact assessment of input use from such policies will be different whether we assume profit maximization alone or we include various objectives in a multi-criteria framework.

Based on the previous assumption, the purpose of this paper is to develop a theoretical model that includes more than a single-objective to analyse input use. Under the Multi-Criteria Decision Making (MCDM) paradigm, through the Multi-Attribute Utility Theory (MAUT), we aim to determine the utility derived from the use of the input to the producers. This analysis will be developed in a twofold manner: the determination of input partial utility, this is, the utility calculated considering one single attribute, and the aggregated utility as the weighted sum of all partial utilities. This theoretical model will further be implemented to analyze water for irrigation as a case study.

2. Theoretical Framework

2.1. Production Theory in a multi-criteria context

Albeit the success of Expected Utility Theory (EUT) as the preferred technique for decision-making modelling after the Second World War, it has been recently criticized on the grounds of its single-attribute formulation. Among these studies we have Gasson (1973), Harper and Eastman (1980), Cary and Holmes (1982), Perkin and Rehman (1994), Willock *et al*. (1999) and Solano *et al*. (2001). All these studies reveal the need of considering more than one objective when modelling farmers' decision-making process.

Thus, it is plausible the assumption of the existence of a utility function with several attributes π, $a_1, \ldots a_n$, and that producers aim to maximize its expected value (Robinson, 1982). This is the core idea behind Multi-Attribute Utility Theory (MAUT):

$$\text{Max } E\,[U\,(\pi, a_1, \ldots a_n)] \qquad [1]$$

If attributes $a_1, \ldots a_n$ are not included in the utility function, the formulation becomes:

$$\text{Max } E\,[U\,(\pi, \varepsilon)] \qquad [2]$$

Where ε is the error term that arises from omitting other attributes in the utility function. As Robinson points out (1982, p.374), the expected utility based on a single attribute cannot accurately predict the producer's behaviour since there are other attributes involved in the decision-making process. In the same line, Anderson *et al*. (1977, p.76) claim "money is not everything", therefore there are problems where it seems appropriate to consider other than monetary objectives.

Acknowledging the convenience of including several objectives to simulate the producer's behaviour, we resort MAUT, an approach largely developed by Keeney and Raiffa (1976), to overcome the limitations of the single-attribute utility function. The multi-attribute approach attaches a cardinal value to each alternative, and considers the aggregate effect of all attributes. Thus, considering r_i attributes from [1] we have:

$$U = U\,(r_1, r_2 \ldots r_n) \qquad [3]$$

Usually, the level of achievement of each attribute can be expressed mathematically as a function of the decision variables, this is, $r_i = f_i(\vec{X})$. When a direction of improvement is assigned to each attribute we refer it as an objective. Thus, decisions under MAUT are made by maximizing U and responding to the set of objectives simultaneously followed by the producer.

Normally, decision variables $(\vec{X})$ included in mathematical models programming are considered as "activities" associated with crops or livestock to which a particular amount of inputs is assigned (i.e. an activity could be the surface devoted to wheat considering certain amounts of labour, agro-chemicals, etc.). This is the way to consider the direct relationship between the level of production and the amount of inputs used, once the real production functions (*f(v)*) are usually not available. In this sense it is possible to translate the level of each activity in the mathematical programming model, $\vec{X}$, into a vector of inputs, $\vec{v}$. Thus, the attributes expressed as a function of the activities, $r_i = f_i(\vec{X})$, can be formulated as well as a function of the inputs used: $r_i = g_i(\vec{v})$. Taking the example of the profit attribute, the new mathematical form as a function of inputs in classical microeconomic theory is: $g_i(\vec{v}) = \pi(\vec{v}) = P \cdot f(\vec{v}) - \sum_{i=1}^{n} p_{v_i} \cdot v_i$.

Hence, from [3] we obtain:

$$U = U\,[g_1(\vec{v}),\, g_2(\vec{v}) \ldots g_n(\vec{v})] = U(\vec{v}) \qquad [4]$$

To seek the maximum profit, the first order condition implies:

$$\frac{\delta U(\vec{v})}{\delta v_i} = 0 \quad \rightarrow \quad MgU_{v_i}(\bar{v}) = 0 \qquad \forall\, v_i \qquad [5]$$

The former expression is a generalization of that proposed by the EUT and the Classical Economic Theory. Let's consider the EUT assumption of a single-attribute utility function, this is, the expected profit utility expression [4] takes the form:

$$U = U\,[\pi] = U\,[\pi\,(\vec{v})] \qquad [6]$$

This corresponds to the EUT approach for modelling the economic agents' behaviour since the maximization of $U\,[\pi\,(\vec{v})]$ resembles the maximization of the expected utility with profit as the single attribute. Moreover, assuming a linear utility function we get $U[\pi(\vec{v})] = \pi(\vec{v})$, but this is the case usually analysed by the Classical Economic Theory, therefore the optimum use of input is determined when:

$$MgU_{v_i}(v) = \frac{\delta U(v)}{\delta v_i} = \frac{\delta\left[\pi(v)\right]}{\delta v_i} = \frac{\delta\left[P \cdot f(\bar{v}) - \sum_{i=1}^{n} p_{v_i} \cdot v_i\right]}{\delta v_i} = MgPV_{v_i} - p_{v_i} = 0 \qquad \forall\, v_i \qquad [7]$$

This EUT point of view, assuming a single-objective, could be considered as adequate when the inputs do not provide any other utility different from their contribution to the profit. However, as we will show later, this is not the case in the agricultural sector, where the inputs provide utility from other attributes different than profit.

In spite of the interest of developing the analysis from expression [5], the main drawback comes from the elicitation of the multi-attribute utility function (Herath, 1981; Hardaker *et al.*, 1997, p.162). In order to simplify this process, some assumptions are made about the mathematical features of the utility function.

Keeney (1974), Keeney and Raiffa (1976) and Fishburn (1982) explain the mathematical requirements to assume an additive utility function. According to them, if the attributes are mutually utility independent the formulation [3] becomes $U= f\{u_1(r_1),\ u_2(r_2),\ ...,\ u_n(r_n)\}$ and takes either the additive form: $U(r_1, r_2, ..., r_n)= \Sigma\ w_i u_i(r_i)$, or multiplicative form: $U(r_1, r_2, ..., r_n)= \{\Pi\,(K w_i u_i(r_i)+\ 1)-\ 1\}/K$, where $0 \leq w_i \leq 1$ and $K= f(w_i)$. If the attributes are mutually utility independent and $\Sigma\ w_i= 1$, then $K= 0$, and the utility function is additive.

Although these conditions are restrictive to a certain extent, Edwards (1977), Farmer (1987) and Huirne and Hardaker (1998) have shown that the additive utility function yields extremely close approximations to the hypothetical true utility function even when these conditions are not satisfied. In this paper we follow the same approach.

The cardinal value of the utility function, obtained by adding the contributions of each attribute, enables us to rank them. The weighting of each attribute expresses its relative importance. In mathematical terms, the multi-attribute utility function (MAUF) takes the following form:

$$U = \sum_{i=1}^{n} w_i u_i(r_k) \qquad [8]$$

where U is the utility value of alternative k, w_i is the weight of attribute i and $u_i(r_k)$ is the value of attribute i for alternative k. As pointed out above, the linear additive function adopted implicitly assumes that the weights (w_i) add up to 1.

Expression [8] in its simplest way takes the form:

$$U = \sum_{i=1}^{n} w_i r_k \qquad [9]$$

The former expression implies linear utility-indifferent curves (constant partial marginal utility), a rather strong assumption that can be regarded as a close enough approximation if the attributes vary within a narrow range (Edwards, 1977; Hardaker *et al*., 1997, p.165). There is some evidence for this hypothesis in agriculture. Thus, Huirne and Hardaker (1998) show how the slope of the single-attribute utility function has little impact on the ranking of alternatives. Likewise, Amador *et al*. (1998) analyse how linear and quasi-concave functions yield almost the same results. As a consequence, we assume this simplification in the elicitation of the additive utility function.

From expression [9] and considering only one variable input we have:

$$U = \sum_{i=1}^{n} w_i g_i(v) \qquad i = 1, ..., n \qquad [10]$$

The overall utility from factor v is the weighted sum of each factor partial utility function (FPUF), this is, the utility that is provided by the factor to each attribute. From this formulation the economic optimum implies:

$$MgU_v = \sum_{i=1}^{n} w_i \frac{d\, g_i(v)}{dv} = 0 \qquad i = 1, ..., n \qquad [11]$$

The former expression for one single product and one input can hardly be applied to the agricultural sector where the multi-output and multi-input processes are common. To handle the modelling problem we resort in the multi-criteria programming techniques. These techniques will allow us to obtain a linear additive MAUF. This utility function permits to reduce the complexity of the decision model to a single objective function (estimated MAUF) maximization programming. In this context, the marginal utility of the input v (MgU_v) in the multi-attribute utility function is calculated from its shadow price. Using the amount of input as a parameter, we will be able to calculate the optimum to reach a shadow price equals to zero (MgU_v=0).

In order to clarify the operational aspects of the MAUT model, we begin explaining the FPUFs ($g_i(v)$). These partial utility functions can exhibit increasing marginal utility ($dg_i(v)/dv$ > 0) or decreasing one ($dg_i(v)/dv$ < 0). As an example, let us consider the water input and two attributes: profit and leisure time. For the first case, as water allowance increases so does profit since farmers opt for more profitable crops, therefore we have an increasing water partial utility function, this is, $dg_{profit}(water)/dwater$ > 0. On the contrary, for the leisure time attribute we have $dg_{leisure\_time}(water)/dwater$ < 0, since more water intensive crops consume more labour.

From the previous example we can see how, in the classical approach, the utility from one input is overestimated when considering profit as the only attribute. The results presented in this paper support this claim. Thus, considering the increasing or decreasing pattern of the partial utility functions, the usual assumptions of increasing utility function ($\frac{\delta U(\vec{v})}{\delta v_i} > 0$) and concavity ($\frac{\delta^2 U(\vec{v})}{\delta {v_i}^2} < 0$) cannot be assumed *a priori* within this multi-criteria context.

2.2. Variability of input use among producers

One central issue in this paper is the assumption of the variability of utility derived from the use of inputs among producers. These differences come both from the shape of the input partial utility function ($g_i(v)$), and the weights (w_i) attached to each attribute in the aggregate utility function.

The Classical Economic Theory, considering $g_{profit}(v)$ as the single attribute, explains the differences of marginal productivity among the economic agents in terms of fixed resources allowance (natural resources, technology, etc.), and therefore the different variable inputs consumption at the optimum. Considering the case of irrigation water, both the mathematical programming models and the econometric models found in the literature clearly focus on structural factors (e.g. farm size and soil quality) to explain differences among producers on their water partial utility functions of the profit attribute, and thus, the difference in water and other inputs use.

We believe this is a partial view of the whole problem of simulating producer's decision-making processes. In a wider multi-criteria context we should consider also the pattern of the FPUFs of all relevant attributes, to continue with the aggregate analysis of them.

Whereas the differences on the FPUFs may be important for two different agricultural areas, these tend to be small for relatively homogeneous areas. Therefore, the significant differences on input use observed in these agricultural systems should be explained in terms of the objective weightings in the aggregate utility function. Let us consider, for example, the existence of two opposite type of producers: those with a profit maximizing behaviour, which implies intensive use of inputs, and those more conservative that prefer lower expected profitability but less variability of returns. They may have similar factor partial utility functions but different weights for each objective resulting in a very dissimilar use of inputs. Behind the variety of weights attached to each objective there are psychological, social and economic reasons, which vary considerably among farmers inside (and outside) any homogenous agricultural area. In this line, there are few studies comparing farmers' objective weighting, among them see for example Sumpsi *et al*. (1997) and Berbel and Rodriguez (1998).

2.3. Multi-criteria technique to elicit multi-attribute utility functions

The methodology adopted for the estimation of multi-attribute utility functions is based on the technique devised by Sumpsi *et al*. (1997) and Amador *et al*. (1998) with further modifications proposed by Gómez-Limón *et al*. (2003).

The objectives weighting obtained by this technique is consistent with the following separable and additive utility function (Dyer, 1977):

$$U = \sum_{j=1}^{n} \frac{w_j}{k_j} f_j(\vec{X}) \qquad [12]$$

where k_j is a normalising factor. Alternatively, the MAUF [12] can be expressed as:

$$U = \sum_{j=1}^{n} w_j \frac{f_j(\vec{X}) - f_{j*}}{f_j^{*} - f_{j*}} \qquad [13]$$

Thus, the utility function [12] is normalized by the difference between the ideal (f_j^*) and the anti-ideal (f_{j*}) of the different objectives, and choosing the mathematical expression of the attributes as their utility function, f_j (X), minus the anti-ideal (f_{j*}).

3. Methodology

3.1. Partial utility functions

The first step aims to determine the main objectives pursued by the farmers in the area of study. We carried out 52 random interviews to identify their objectives. According to the previous literature and to the answers given by farmers, we assume that the main objectives in the area are:

- *Maximization of total gross margin* (TGM), as a proxy for profit in the short term.
- *Minimization of risk*, measured as the variance of the TGM (VAR). The risk is thus computed as $\vec{X}'\cdot$[Cov]$\cdot\vec{X}$, where [Cov] is the variance-covariance matrix of the crop gross margins, and $\vec{X}$ is the crop decision vector.
- *Minimization of total labour input* (TL). This objective implies not only a reduction in the cost of this input but also an increase in leisure time and the reduction of managerial involvement.
- *Minimization of working capital* (K). This has the aim of reducing the level of indebtedness.

Once the attributes of the utility function (f_j ($_{-}$)) are defined we need to link the activity level with the use of inputs ($g_i(v)$). Next, focusing on water for irrigation, we maximize the partial utility functions taking the water allotments as a changing parameter. At the optima we establish the maximum (or minimum) level of that particular attribute for a given amount of water and determine both the water partial utility (the value achieved by the objective function) and its marginal partial utility (its shadow price).

To build the models the following constraints were included:

- The sum of decision variables (surface devoted to each crop) is equal to or lower than the farm size.
- European Common Agricultural Policy constraints (set-aside requirements and sugar-beet quotas).
- Rotational constraints as expressed by the farmers questioned in the survey.
- Market constraints that limit the amount of risky crops according to traditional practices.

The water partial utility functions will show that the differences among producers are relatively small. These come mainly from soil quality and CAP constraints (like sugar beet quotas), since technology and factors market are alike for all of them.

3.2. Multi-attribute utility functions

Following the methodology explained in Section 2.3 the MAUF in [13] becomes:

$$U = w_1 \frac{TGM(\vec{X}) - TGM_*}{TGM^* - TGM_*} + w_2 \frac{VAR_* - VAR(\vec{X})}{VAR_* - VAR^*} + w_3 \frac{TL_* - TL(\vec{X})}{TL_* - TL^*} + w_4 \frac{K_* - K(\vec{X})}{K_* - K^*} \quad [14]$$

This formulation, that expresses the different weighting (w_i) of the objectives by the farmers, explains most of the variability on water use for irrigation. Thus, we can determine the relationship between the amount of water used in the simulation and the utility provided to the farmers (*U*(*water*)). To do so, we have proceeded as previously explained in the assessment of the partial utility functions ($g_i(v)$) by including water as a parameter and maximizing the expression [14]. Moreover, we compare the utility functions (*U*(*v*)) disparity among producers and the amount of water at the optimum.

3.2. Cluster analysis

The sample size, 52 farmers, makes cumbersome the amount of data to determine the individual factor partial utility functions (FPUFs) and the aggregate utility functions (MAUFs). Therefore, it was convenient to gather farmers into relatively homogeneous groups. Thus, we study the marginal and aggregate utility of the representative farms of each group as well.

To reduce the number of cases of study we use the cluster analysis. This technique classifies cases into relatively homogeneous groups. Cases in each cluster tend to be similar to each other and dissimilar to cases in the other clusters (Malhotra and Birks, 1999). For this purpose, we have considered the objectives weights (w_i) as classification variables. Thus, the groups or cluster obtained can be considered to include farmers with a similar behavioural pattern (similar MAUFs).

The selected clustering method was Ward's procedure, or method of the variance. Furthermore, the distance used to measure the difference between farmers' w_i vectors has been the squared Euclidean distance.

Each cluster obtained in this way can be considered as a "farmer-type" to be analyzed separately. In order to simulate the behaviour of these virtual farmers, it is supposed that each one has as objectives weights (w_i) the means of all real farmers' weights included in their respective cluster.

4. Case study

The case study is a community of irrigators located in Northern Spain, *Los Canales del Bajo Carrión,* in the county of Palencia. This community has 6,554 irrigated hectares and 889 farmers, with an average farm size of 7.4 ha. It has a typical continental climate, 780 m above sea level, with long, cold winters and hot, dry summers. Rain falls mostly in spring and autumn. During winter the main crops are wheat and barley, in the summer mainly maize, sugar beet and sunflower. During the summer it is necessary to irrigate to bring the crops to the harvestable stage.

The main irrigation systems are furrow for most crops and spraying for sugar beet. In decreasing order of importance, the average range of crops is winter cereals, maize, alfalfa, sugar beet, and sunflower.

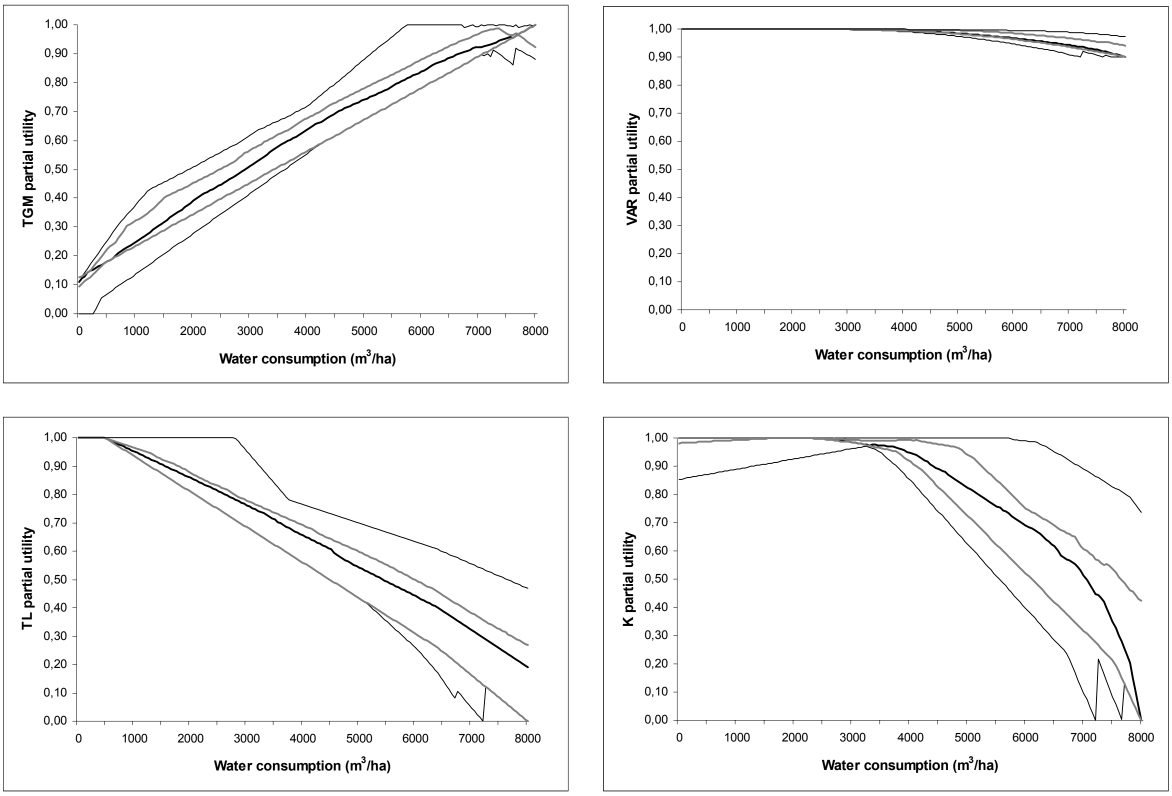
5. Results

5.1. Partial utility functions

We built the 52 individual models to be run with the proposed four objectives (max. TGM, min. VAR, min. TL and min. K). Thus 52x4 individual models have been solved using water availability as a parameter from 0 to 8,000 m^3/ha at intervals of 50 m^3/ha. Results of this computational effort are the individual FPUFs (g_i(*water*)). Figure 1 shows the lower and upper envelope of the 52 partial utility curves. In between, the lower and upper quartiles and the median are also shown.

As we can see, the proximity of the envelopes suggests relatively homogenous FPUFs for the different farmers. For the profit attribute it is observed that the differences on water productivity ($g_{\text{profit}}(water)$), as proposed by the Classical Economic Theory, can hardly explain the observed variability of farmers' behaviour. The curves show, as expected, the increasing utility of water for the profit attribute and the decreasing utility for the other attributes.

The shape of the partial utility functions has two consequences. First, the shape (increasing/decreasing features) of the aggregate utility functions will depend on the weights attached to each attribute by the farmer. Thus, the conventional assumptions proposed in [5] are not necessary to be true. In any case, the monotony characteristics of the utility functions are not a critical point to invalid the theoretical model developed to explain factor use. Second, the utility provided from the use of the input under this approach will be lower than



that provided under the single-attribute classical approach.

Fig. 1. Water partial utility functions ($g_i(water)$).

5.2. Estimates of the attribute weights

Following the methodology explained in Section 2.3, we obtained the weights attached to the four attributes for the 52 farmers. According to the results, the maximization of profit appears as the most important objective for the 47.8%, followed by the minimization of risk (35.7%), and the minimization of the working capital (16.5%). The other objective, the maximization of the leisure time, was not considered relevant for the farmers since the estimated weight was zero. Figure 2 shows the weight cumulative distribution function for the three objectives included in the individual MAUFs.

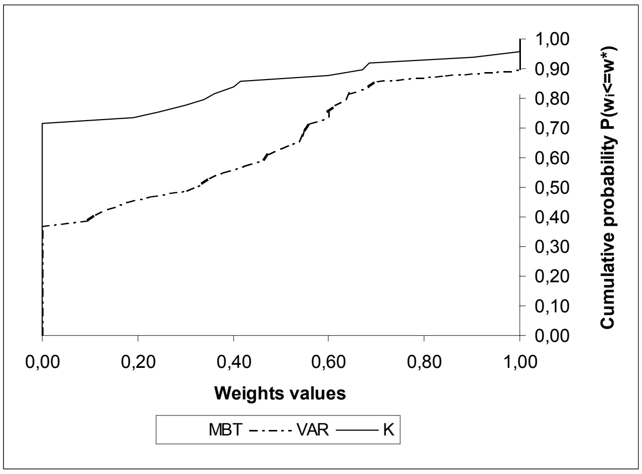


Fig. 2. Cumulative probability distributions of the weights (w_i).

These results suggest that the maximization of profit and the minimization of risk are the most important objectives for most farmers. Yet, the analysis should not be restricted to these two objectives, as proposed by the E-V analysis (EUT), since the exclusion of other objectives, although less important, may result in biased estimates of the input use.

5.3. Multi-attribute utility functions

Once the weighting vector has been calculated for each producer, we estimate the aggregate utility function changing, as previously, the water allowance. Similarly, Figure 3 presents the maximum, upper quartile, median, lower quartile and minimum curves.

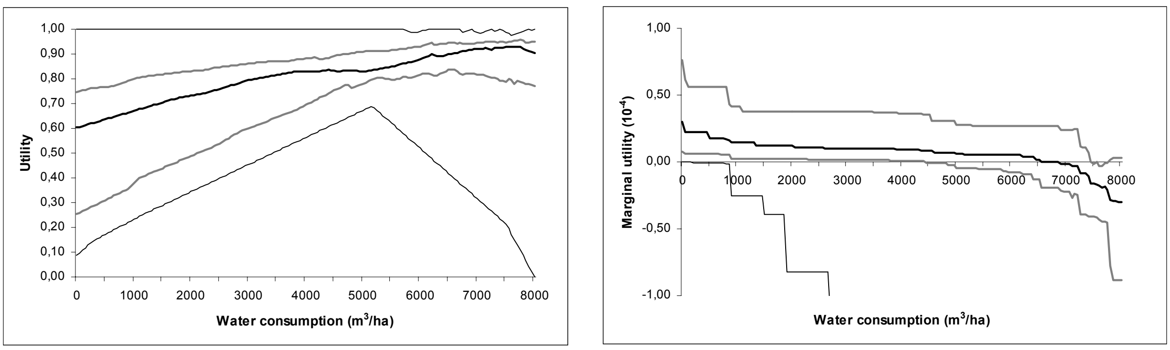


Fig. 3. Aggregate utility functions (U) and Marginal utility functions (MgU).

We can draw some conclusions from Figure 3. First, the aggregate utility from the use of water varies notably from one producer to another. The main reason behind these differences comes from the producer's weighting of the objectives. Second, the marginal utility curve suggests that the optimum amount of water (MgU_{water}=0) depend on the type of producer. Thus, 25% of them locate the optimum at a point of consumption lower than 4,500 m^3/ha. The next two quartiles consume in an interval of 4,500 to 6,500 m^3/ha, and 6,500 to 7,500 m^3/ha, respectively. The last quartile of farmers' demands more than 7,500 m^3/ha. These results indicate the great variability of water consumption among producers in the same region.

5.4. Analysis of representative cases

Once the dendrogram has been obtained, we have opted for selecting four groups of farmers, that can be labelled as follows:

- Cluster 1: "*Young commercial farmers*".
- Cluster 2: "*Cattle-raising farmers*".
- Cluster 3: "*Very conservative farmers*".
- Cluster 4: "*Large conservative farmers*".

The following table summarizes the average weighting of each attribute for the previous clusters. It also provides the normalized aggregate utility function calculated from expression [14].

Table 1

Average weighting for each objective and cluster. Aggregate utility function

		Cluster			
		Young commercial farmers	Cattle-raising farmers	Very conservative farmers	Large conservative farmers
Percentages	Maximization of profit	86.9	17.1	2.6	39.3
	Minimization of risk	6.5	13.8	97.4	60.7
	Minimization of total labour	0.0	0.0	0.0	0.0
	Minimization of working capital	6.6	69.1	0.0	0.0
Normalized	Maximization of profit	290.5	52.8	87.4	845.0
	Minimization of risk	-0.00019	-0.00041	-0.03163	-0.00722
	Minimization of total labour	-	-	-	-
	Minimization of working capital	-35.9	-356.0	-	-

Once the utility functions for each cluster have been determined, they have been used to estimate the optimum solutions for different water allowance. Thus, we obtain the water utility and marginal utility curves for each group of farmers. Figure 4 presents the results.

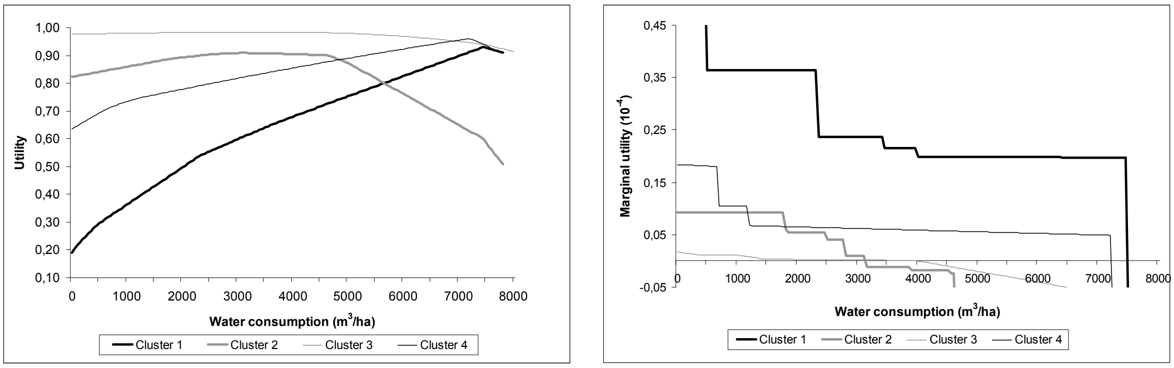


Fig. 4. Aggregate utility and marginal utility curves for each cluster.

From the previous figure we find important differences in the aggregate utility functions for each cluster, yet all have in common a function that is increasing and concave. Cluster 1 has the highest utility for the water input due to the importance attached to the maximization of profit. Alternatively, Cluster 2 and 3, with a lower weight for the former objective, have also lower water utility.

In Figure 4, where marginal utility functions are plotted, we see how the optimum (MgU_{water}=0) is reached at different points. At the extremes, Cluster 1 optimizes its utility function with MgU_{water}=0 for an amount of water equals to 7,500 m^3/ha, whereas Cluster 2 needs only 3,150 m^3/ha. Thus, as explained previously, those farmers with their highest weight attached to the maximization of profit demand more water. On the opposite, the more conservative farmers opt for a lower use of this input, assigning a higher weight to the minimization of risk and the minimization of working capital.

These results suggest that the variety of utility functions, this is, the different weights attached to the objectives in the utility function, explain the large disparity of input use (water in our case) among farmers belonging to a relatively homogenous agricultural area.

6. Conclusions

There are two main conclusions from the results obtained in this study:

- The differences observed in the use of inputs by farmers, water in our particular case, should be explained not only from their structural endowments (soil, climate, etc.) and the access to other production factors (machinery, production quotas, etc.), but also from their respective utility functions in a multi-criteria context. Thus, relatively homogeneous group of farmers, in terms of production possibilities, differ greatly in their behaviour as a consequence of different multi-attribute utility functions.

- From a practical point of view, the greatest challenge posed by the Multi-attribute Utility Theory is the elicitation of the mathematical form of the function. This limitation can be overcome by assuming some simplifications, this is, the assumption of additive utility functions. The multi-criteria approach selected in this paper allows the elicitation of the utility functions in a straightforward manner.

With respect to the practical findings of the paper about the use of the water for irrigation, we stress their importance for the implementation of the water demand policies. This approach enables a different analysis for each type of farmers in order to respond to the variety of utility functions. From this analysis, we conclude that the effect of a water pricing policy for irrigation on farm income and water consumption will differ from one group of farmers to another, rejecting therefore the traditional assessment of similar responses.

Likewise, this methodology improves the understanding of water markets since the accurate valuation of the input, its utility for the producer, is a requirement to assess the willingness to pay for it (see for example Arriaza *et al.*, 2002).

Finally, the elicitation of aggregate utility functions for relatively homogeneous groups of farmers can be used to assess the impact of the irrigation modernization policies, in terms of utility really obtained by the farmers for this technological change, instead of analysing it exclusively via factor price changes.

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