Chapter #

MCDM FARM SYSTEM ANALYSIS FOR PUBLIC MANAGEMENT OF IRRIGATED AGRICULTURE

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Abstract: In this chapter we present a methodology within the multi-criteria paradigm to assist policy decision-making on water management for irrigation. In order to predict farmers' response to policy changes a separate multi-attribute utility function for each homogeneous group, attained applying cluster analysis, is elicited. The results of several empirical applications of this methodology suggest an improvement of the ability to simulate farmers' decision-making process compared to other approaches. Once the utility functions are obtained the policy maker can evaluate the differential impacts on each cluster and the overall impacts in the area of study (i.e. a river basin) by aggregation. On the empirical side, the authors present some studies for different policy instruments including water pricing, water markets, modernization of irrigation systems and a combination of them.

Key words: Multi-Attribute Utility Theory; Water management; Irrigation; Policy analysis.

1. INTRODUCTION: IRRIGATED AGRICULTURE AND THE MCDM PARADIGM

Since irrigated agriculture is simply a type of agriculture, the application of most of the literature on Multicriteria Decision Making (MCDM) for agricultural systems is straightforward (see Romero and Rehman, 2003). However, there are some special characteristics related to the farmers' decision-making processes:

1. The availability of water for irrigation allows farmers to obtain higher yields and the possibility of growing a larger amount of crops. Thus,

within this productive framework, the farmers' decision-making process in irrigated agriculture is more complex than that in rainfed farming.

2. Water is not merely an input of irrigated agricultural systems but also a scarce natural resource with alternative destinations: human consumption, the general environment, industry and agriculture. Therefore, water allocation policies are of decisive importance in terms of economic efficiency, territorial equilibrium and social equity.
3. Irrigated agriculture consumes much more inputs (labour, chemicals, machinery, etc) than its rainfed counterpart. This results in the intensification of externalities, both positive and negative, that results in policy implementation conflicts between the farmers on one side (who primarily seek to maximize profit and reduce risk) and the public sector on the other (minimizing environmental impact, maximizing rural employment, etc.).

Furthermore, the qualitative importance of irrigation on agriculture is clearly reflected in its contribution to agricultural world production: although only 18% of the world agricultural land (250 mill. ha) is under irrigation, irrigated agriculture accounts for 80% of global water consumption (3000 km^3/year) and produces 43% of the world's food supply (more than 50% in monetary terms), according to official statistics (FAO, 2000).

All the above observations justify the proliferation in recent years of scientific papers by agricultural and resources economists, as well as civil engeenering studies. Many experts in these fields have opted for MCDM as the methodological guide to analyze the agricultural systems. This is why a chapter in this book devoted to the application of MCDM to irrigation is also justified.

The aim of this chapter is thus to present a suitable methodology for guiding the decision-making process of the authorities regarding efficient water management for irrigation, subject to economic, environmental and social sustainability. To achieve this end, the authorities have a wide variety of policy instruments for agriculture (subsidies, tariffs, etc.) and water (pricing, markets, etc.). However, given the multidimensional implications of welfare optimization, more traditional approaches (e.g. cost-benefit analysis) may be overwhelmed by the complexity of the decision-making process. This work supports the use of multicriteria techniques to simulate policy scenarios, in particular, the integration of results in a multiattribute utility function that ranks all the alternatives according to the the preferences of society, enabling us to determine in advance the suitability of individual policy instruments.

This chapter is organized into six sections. Section 2, following the introduction, presents a review of the literature on MCDM as applied to irrigated agriculture. Section 3 highlights some challenges faced by these simulation techniques in order to become a useful tool in policy decision-making. The methodological contribution required to meet this objective is outlined in Section 4. Section 5 analyses some empirical applications following this approach. Finally, we draw some conclusions in Section 6.

2. IRRIGATED SYSTEMS, DECISIONS, DECISION-MAKERS AND DECISION CRITERIA

2.1 Irrigated systems and decision-making

As pointed out above, there are numerous empirical applications of MCDM techniques to analyse irrigated agricultural systems. We can classify these into three levels of aggregation: river basin, irrigated area and farm. For each level, the type of problem analysed and the approach selected has been different.

The first use of MCDM techniques, beginning in the seventies, corresponded to the river basin level. In most cases, the problems analysed were related to water use planning: investment appraisal, water allocation to various economic sectors, and within the agricultural field, to irrigation areas and crops. More recently, as environmental regulations have become stricter, many studies have focused on conflicting environmental, economic and social criteria in these particular agricultural systems.

From a methodological point of view, most MCDM techniques are covered in these studies. It is also important to note that in all of them the basin authority is the only decision-maker and that it seeks to maximize the benefits to society as a whole through its decisions. In this sense, the public criteria can be categorized as follows:

- *Economic development*: Economic efficiency, national economic development (growth rates of national income, inflation) and regional economic development (direct income, territorial equity, market development).
- *Social welfare*: Social equity (employment level, income redistribution) and self-sufficiency in food production.
- *Environmental protection*: Water quality impacts control (nitrogen and phosphorus discharges, increasing biological oxygen demand load, groundwater level), control of soil quality impacts (salinisation, erosion), other ecological impacts (biodiversity, energy balance) and reservoir safety (sediment, flood impact on dams).

In a multi-objective analytical framework, the objective function to be considered in such problems is usually defined in such a way as to simultaneously maximize economic development and social welfare and to minimize environmental impacts, considering the institutional framework, and the social, physical, economic and environmental limitations included in the set of constraints.

At the second level of aggregation, the irrigation area, in most cases we find again the public sector as the sole decision-maker. There are studies on water dosage and optimum crop distribution, irrigation technology, irrigation schedules and environmental problems. As in the studies at basin level, the public criteria in the irrigation areas include economic (profitability of crops, cost of irrigation systems, etc.), social (equity or rural employment) and environmental aspects (water volume, water quality after irrigation, land capability/suitability, efficiency of water usage, resistance to floods or droughts, energy balance, etc.), applied to relatively homogeneous geographical areas.

At farm level, most of the MCDM applications focus on crop-mix optimization, following, unlike in the other two levels of aggregation, private criteria: profits (level of income and costs), risk avoidance or farm labour (as a proxy for farmer's leisure time). For further details see Hayashi (2000).

2.2 Normative models *vs*. descriptive models

Decision models of irrigated agricultural systems shows a clear distinction between the most frequent normative and a very small number of descriptive models. Normative models, however, are less favoured for use as a centrally planned approach; nowadays economists place greater importance on the decisions made by private economic agents. In this context, therefore, normative optimum solutions are rarely achieved by any society. We cannot conclude from the previous statement that normative solutions are pointless. On the contrary, they show the potential of agricultural systems to satisfy the needs of society. It follows that policy instruments should be selected on the basis of inducing those farmers' responses, on an aggregated level, that are as close as possible to the normative solutions. Descriptive models, however, may help us to arrive at better explanations (backward use) and predictions (forward use) of farmers' responses to policy changes.

In order to develop descriptive models, neo-classical economic theory supports the single-objective maximization behaviour of economic agents. Nevertheless, it has frequently been observed that the optimum solution of models developed within this theoretical framework do not seem to adequately match the observed behaviour of producers, which suggests that there is a need for more complex models capable of providing more accurate results.

A number of studies have rejected the hypothesis that farmers seek to maximize profits only, arguing that producers seek to optimise a broader set of objectives such as the maximization of leisure time, the minimization of management complexity and working capital, etc. In this context, we may mention recent studies by Willock *et al*. (1999), Costa and Rehman (1999), Solano *et al*. (2001) or Bergevoet *et al*. (2004). The implication is clear: when modelling farmers' decision-making processes (building models capable of simulating farmers' behaviour) it is essential to take more than one criterion into account.

Therefore, it is necessary to put forward more realistic hypotheses based on the psychology of decision-makers. One alternative, the one proposed in this work, tackles the MCDM decision-making problem via Multi-Attribute Utility Theory (MAUT). This advances a set of descriptive models that assume optimizing behaviour on the part of the farmer and present a mathematical formulation of his/her preferences in a multicriteria context; that is, a multi-attribute utility function (MAUF), as we explain in the following section.

3. FRAMEWORK FOR MODELLING IRRIGATED AGRICULTURE SYSTEMS

Most irrigated agriculture is located in economies that are characterized by growing demand for water, a limited long-term supply, increasing operating costs of storage and distribution, growing competition among regions for alternative uses and rising environmental problems (negative externalities). However, the whole question is more a problem of water management and inefficiencies than an input shortage (Randall, 1981).

In order to partially overcome these limitations, water policies have shifted from an exclusively supply-side approach toward a more integrated analysis that includes demand-side policies. In this context, water policies aim to allocate this natural resource according to socio-economic efficiency criteria via three main policy instruments: water pricing, implementation of water markets and subsidies to improve the technical efficiency of the distribution infrastructure.

In the search of water allocation efficiency, one of the first initiatives to be taken was the transfer to the producer of part of the total cost of providing water. The second instrument, the implementation of water markets, may help to improve this allocative efficiency in a decentralized manner, as well as reducing the effects of water scarcity. Finally, we have the provision of subsidies to modernize the distribution infrastructure and the irrigation systems in the farms. The suitability of each instrument of water policy depends on the social, economic and environmental impact upon the agricultural systems, via the farmers' responses. Therefore, if we aim to build functional simulation models for the regional or national authorities, all these three aspects need to be considered in the analysis.

Furthermore, it is worth noting that in addition to environmental (water) policy on irrigation there is another crucial policy to be considered: the agricultural policy. In this respect, agricultural policies have evolved to meet both internal (e.g. environmental concerns, budget limitations, bio-technological advances, etc.) and external demands (e.g. agricultural market liberalization). In any case, it is important to provide these types of models in order to assist policy-makers in their assessments of the adequacy of alternative instruments.

Within this social and political framework, the methodological framework proposed to achieve the goal set out in this paper (modelling irrigated systems for policy decision support) is displayed graphically in Figure 1. This methodological outline is based on five stages, which are further explained in the next section.

4. METHODOLOGICAL APPROACH

4.1 Farm typology definition

Modelling agricultural systems at any level other than that of the individual farm introduces the problem of aggregation bias. The introduction of a set of farms in a unique programming model overestimates the mobility of resources among production units, allowing combinations of resources that are not possible in the real world. The final result of these models is that the value obtained for the objective function is biased upward and the values obtained for decision variables tend to be unachievable in real life.

This aggregation bias can only be avoided if the farms included in the models fulfil certain criteria regarding homogeneity (Day, 1963): technological homogeneity (same possibilities of production, same type of resources, same technological level and same management capacity), pecuniary proportionality (proportional profit expectations for each crop) and institutional proportionality (availability of resources to the individual farm proportional to average availability).

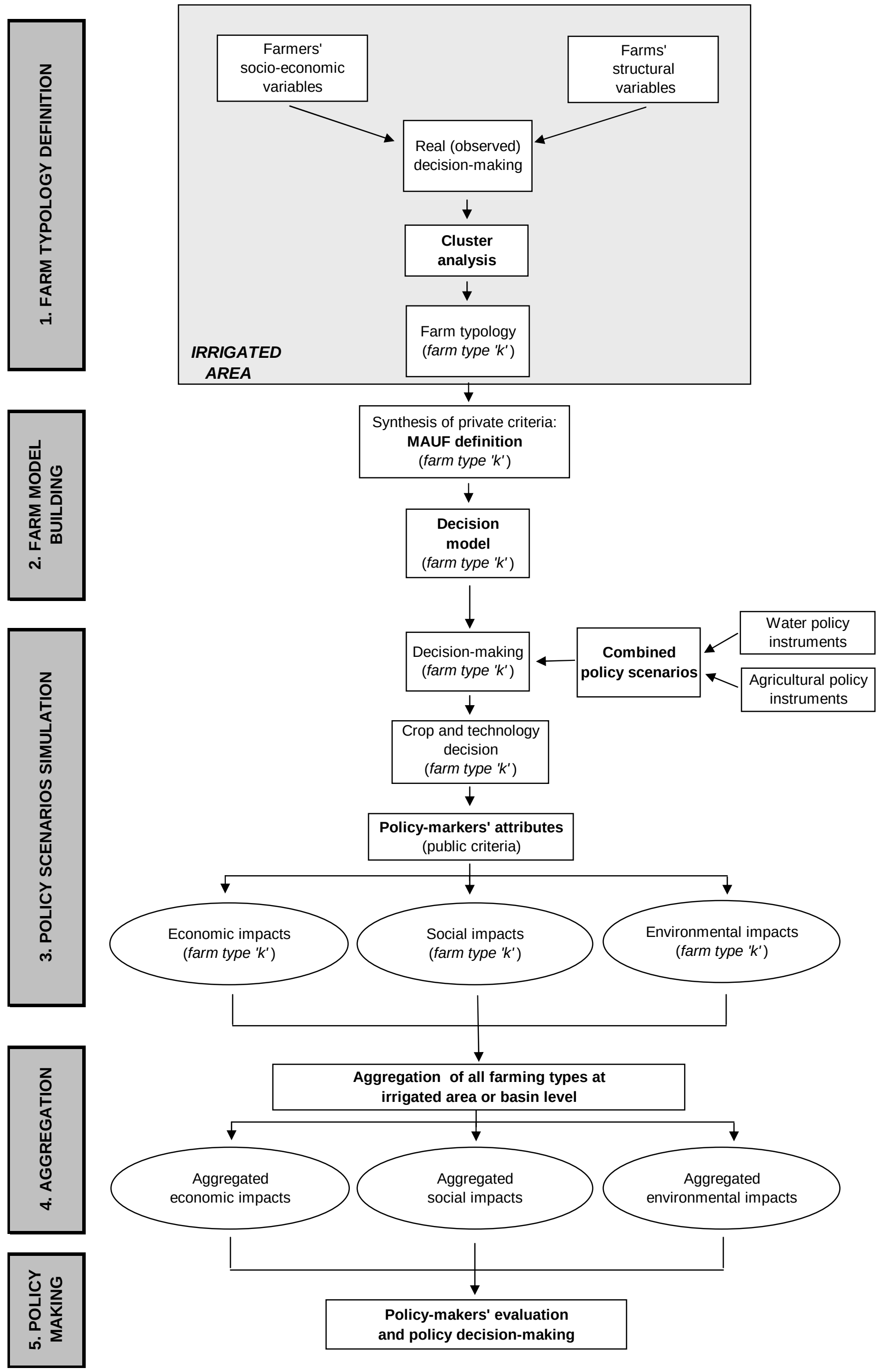

Figure #-1. Methodology diagram

This requirement of homogeneity brings us to consider the irrigated unit as the basic element to be analysed. These units are relatively small areas (ranging usually from 1,000 to 20,000 hectares) that can be regarded as fairly homogeneous in terms of soil quality and climate, and in which the same range of crops can be cultivated with similar yields. Furthermore, the set of farms that comprise each of these agricultural systems usually operates the same technology at a similar level of mechanization. Moreover, given efficient capital and labour markets, the constraints included in modelling this system have been limited to agronomic requirements (crop rotations) and the restrictions imposed by the agricultural policy, which are similar for all farms. All these facts allow us to assume that the requirements regarding technological homogeneity, pecuniary proportionality and institutional proportionality are basically fulfilled.

We might thus conclude that particular irrigated areas could be modelled by means of a unique linear program with relatively small aggregation bias, but this is based upon the assumption that the sole criterion on which decisions are based is profit maximisation. When we adopt a multi-criteria perspective, a new homogeneity requirement emerges if we wish to avoid aggregation bias; viz., *homogeneity related to choice criteria*. We assume that decision criteria are primarily based on the psychological characteristics of decision-makers, which differ significantly from farmer to farmer. According to this perspective, the differences in decision-making (crop mix) among farmers in the same production area must be primarily due to differences in farmers' objective functions, rather than other differences related to farm characteristics regarding either crop profits or disparities in resources requirements or endowments.

In order to avoid aggregation bias resulting from lumping together farmers with significantly different objective functions, a classification of farmers into homogeneous groups with similar decision-making behaviour (objective functions) is required. As Berbel and Rodríguez (1998) have pointed out, we can assume that in a homogeneous area (irrigated unit), differences in the crop mix are mainly caused by farmers' different management criteria (utility functions) rather than by other constraints such as land quality, capital, labour or water availability. Thus, following these authors, the observed area (as percentages) devoted to individual crops, considered as proxies for the real criteria, can be used as classification variables to group farmers using the cluster technique.

Finally, it is worth noting that the homogeneous groups obtained in this way can be regarded as 'fixed' in the short and medium terms. As noted above, the decision criteria are based on psychological features of the decision-makers, which is why they may be regarded as structural characteristics of producers. These psychological features, and thus the criteria, are unlikely to change in the near future. This means that the selection variables chosen allow farmers to be grouped into clusters that are robust to changes in the policy framework. In other words, once the homogeneous groups of producers have been defined for actual data (crop mix), we can assume that all elements (farmers) of each group will behave in a similar way if policy variables change.

4.2 Farm type model-building

As Figure 1 shows, the first stage of the modelling process produces a set of homogeneous groups of farmers, while the second builds the mathematical models for each farm type, consisting of a specific multi-criteria model at farm-type level. This enables independent simulations based on the decision-making behaviour of the various groups of farmers to be run. For this purpose, the basic elements of any mathematical model; i.e. decision variables, objective function and set of constraints need to be outlined.

While the choice of crop areas as a *decision variable* does not cause any problem (observing crop diversity in the area studied is sufficient), the objective function and constraints require more detailed analysis.

4.2.1 The Multi-Attribute Utility Theory approach

In view of the evidence on how farmers take decisions while trying to simultaneously optimise a range of conflicting objectives (see Section 2.2), we propose Multi-Attribute Utility Theory (MAUT) as the theoretical framework for the MCDM programming to be implemented. The aim of MAUT is to reduce a decision problem with multiple criteria to a cardinal function that ranks alternatives according to a single criterion (Keeney and Raiffa, 1993). Thus, the utilities of n attributes are captured in a quantitative way via a utility function, mathematically, $U = U(r_1, r_2, ..., r_n)$, where U is the Multi-Attribute Utility Function (MAUF) and r_i are the attributes regarded by the decision-maker as relevant in the decision-making process.

In spite of the interest of developing the analysis from the above expression, the main drawback to this approach comes from the difficulty of eliciting the multi-attribute utility function (Hardaker *et al.*, 1997, p.162). In order to simplify this process, some assumptions need to be made about the mathematical features of the utility function.

Fishburn (1982) and Keeney and Raiffa (1993) have explained the mathematical requirements for the assumption of an *additive* utility function. From a practical point of view, the basic condition that needs to be satisfied is that the attributes considered r_i should be mutually utility-independent.

Although this condition is somewhat restrictive, Edwards (1977), Farmer (1987), Huirne and Hardaker (1998) and Amador *et al*. (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. For this reason, additive utility functions for modelling farmers' behaviour have been widely employed.

Given this justification for the use of the additive utility function, we take the further step of assuming that the individual attribute utility functions are *linear*. Hence, the MAUF expression becomes:

$$U = \sum_{i=1}^{n} w_i r_i \qquad (1)$$

This 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 and Hardaker *et al*., 1997, p.165). There is some evidence for this hypothesis in agriculture. Thus, Huirne and Hardaker (1998) have shown how the slope of the single-attribute utility function has little impact on the ranking of alternatives. Likewise, Amador *et al*. (1998) analysed how linear and quasi-concave functions yield almost the same results. We therefore adopt this simplification in the elicitation of the additive utility function. Thus, MAUFs with this shape may be regarded as objective functions for the different farm-type models.

4.2.2 The objective function: MAUF elicitation technique

To estimate the relative weightings w_i we select a methodology that avoids the necessity of interacting directly with farmers, and in which the utility function is elicited on the basis of the revealed preferences implicit in the real values of decision variables (i.e. the actual crop mix). The methodology adopted for the estimation of the additive MAUFs is based on the technique proposed by Sumpsi *et al*. (1997) and extended by Amador *et al*. (1998). It is based upon weighted goal programming. To avoid unnecessary repetition, we refer to these papers for details of all aspects of this multi-criteria technique. Here, we wish only to point out that the results obtained by this technique are the weights (w_i) that imply utility functions that are capable of reproducing farmers' observed behaviour. As Dyer (1977) demonstrates, these weights are consistent with the following separable and additive utility functions:

$$U = \sum_{i=1}^{q} \frac{w_i}{k_i} f_i(x) \qquad (2)$$

where k_i is a normalising factor.

Applying this technique to each farm-type enables us to estimate the different objective functions in each case.

4.2.3 Model constraints

Finally, it is worth noting that the farm-types' decision-making models need to be completed with the constraints that must be satisfied. These constraints are mainly due to the structural characteristics (climate, soil fertility, market limits, agricultural policy requirements, etc.) of the farms that are similar for all farm types in a particular irrigated area. Only slight differences could be fixed by clusters (farm size, production quotas, etc.) according to the data obtained in the farm survey implemented for primary data gathering.

In sum, the descriptive decision model at farm level can be set out as follows:

$$\text{Max} \quad U = \sum_{i=1}^{q} \frac{w_i}{k_i} f_i(x) \qquad (3)$$

$$\text{Subject to:} \quad g_j(x) \le b_j \quad \forall j$$

where $g_j(x) \le b_j$ represents the set of constraints applied to each group (cluster) of farmers (land, rotational, market and agricultural policy constraints, etc.).

4.3 Simulation of policy scenarios

4.3.1 Definition of policy scenarios

The third stage of the methodology proposal simulates the policy scenarios. For this purpose the scenarios must already have been defined. Here it is essential to clearly identify the instruments to be implemented, both in a qualitative and quantitative sense. For example, in case of water pricing, the control method employed should be clarified: e.g. per cubic metre, mixed (volume and irrigated hectare), by blocks, etc., in addition to the price.

4.3.2 Simulation of farm-type behaviour

Once we have established the policy scenario to be analysed, the farm-type models should modify the decision variables and parameters as appropriate. At this point, it is necessary to address certain issues.

It is worth pointing out that the estimates of the *utility functions* have been obtained by farm models that have been fed with data gathered for the current situation. In doing so we assume that the utility functions obtained at this point can be regarded as a structural feature of each cluster. As these objective weightings are the result of the farmers' own attitudes, it is reasonable to assume that they will remain constant in both the short and medium terms. This assumption is a key point of the methodology, since the estimated utility functions are assumed to be those that the farmers in each cluster will attempt to maximize in the future, for any scenario that they will be likely to face. This assumption is based upon the hypothesis that values reflected in the MAUF are stable characteristics of decision-makers.

Furthermore, in order to simulate the impacts of different scenarios, *decision variables* to be included in the tailored decision-making models should consider all the ways in which farmers are likely to adapt to any given policy scenario. Potential changes in the institutional framework should include at least the following:

1. Changes in the crop plans, allowing irrigated *vs.* rain-fed (no irrigation) crops, and annual *vs.* perennial crops. The fallow alternative (abandonment of agriculture) should be also considered.
2. Implementation of water stressing (deficit irrigation).
3. Changes in farming technology: irrigation technology (taking into account the substitution of surface irrigation by sprinklers or drip whenever possible), tillage technology, etc.

Once the adapted models have been built, farm-type behaviour as a reaction to policy scenarios is simulated by simply running the models. This identifies the decisions likely to be taken (i.e. crop mixes and technology) by the different clusters of irrigators.

4.3.3 Policy-makers' attributes

The crop-technology plans obtained by the simulation models are intermediate tools for policy-makers, who are primarily interested in the values that result from the adoption of a series of public criteria (see section 2.1). Nevertheless it is important to note that these policy criteria are attributes obtained in the simulated private decision-making process, but they are called attributes just because they do not belong to farmers' private objective function; neither they are considered as goals or constraints in simulation models.

Nowadays, the political paradigm in agriculture, as in any other industry, is to achieve *sustainability*. This global criterion may be decomposed into three main dimensions: economic, social and environmental sustainability. When modelling policy alternatives, the level of achievement of these criteria requires the use of *indicators*, as attributes obtained by the simulation models. Although there are many indicators of sustainability (Brouwer and Crabtree, 1998; OECD, 1999; Rigby *et al*. 2001), the selection among them depends greatly on the policy-makers' own preferences.

4.4 Aggregation

Albeit the particular study of the results by group of farms (differential assessment of impacts) is relevant, the policy choices are based on the aggregated analysis. Therefore we need to extend the conclusions to the area or river basin level, aggregating each weighted impact by its relative hectarage.

4.5 Policy makers' decision-making

Once the social utility function that includes all the relevant criteria has been defined, the methodology ends with the policy choices. Assessment of the alternative policy instruments is based on the value achieved in the utility function of society as a whole, in which all the public criteria considered (values reach by the selected indicators) are taken into account.

Although several MCDM techniques to attain this last step are available, the authors favour the *Analytical Hierarchy Process* (AHP), developed by Saaty (1980). Its straightforwardness and the utility of the public criteria ranking are the reasons for our choice.

5. APPLICATIONS

This section presents some of the authors' empirical applications of this methodology. They include studies of water pricing, water markets and modernization of irrigation systems.

5.1 Water pricing

One of the most ambitious applications of this methodology can be found in the European Project WADI (2000-2004). The ultimate objective of this research project is the design of a tool that can be used to assist policy-makers in pricing water, following the approval of the Water Framework Directive (2000), which obliges all State Members to use economic instruments and to recover the costs of providing water services (i.e. water pricing as a major instrument of water policy inside the EU). Specifically, the norm states that "*Member States shall take account of the principle of recovery of the costs of water services, including environmental and resource costs*".

As Figure 1 explains, the models used in the WADI project are based on the definition of farming types by cluster analysis (or any other technique), based in each case on the particular farming model, and finding weights for MAUT objective functions. A first result worth pointing out is the wide differences that have been found among farmers' objective weightings. An example of these variations is shown in Table 1, which illustrates the results from some Spanish irrigated areas located in the Duero and Guadalquivir basins. In all cases crops and natural conditions are homogeneous within the irrigated unit, and variations in behaviour are due mainly to the socio-economic characteristics of individual farmers.

Table #-1. MAUF weights for selected Spanish locations

Irrigated area	Farming model	Label	Weights			
			Max. gross margin	Min. variance (risk)	Min. total labour	Min. working capital
Canales Bajo Carrión *(Duero)*	CBC1	Part-time farmers	0.33	0.67	0.00	0.00
	CBC2	Livestock Farmers	0.43	0.57	0.00	0.00
	CBC3	Small commercial farmers	0.71	0.07	0.00	0.22
	CBC4	Risk-averse farmers	0.66	0.34	0.00	0.00
Canal del Pisuerga *(Duero)*	CPI2	Risk diversification farmers	0.00	1.00	0.00	0.00
	CPI2	Young commercial farmers	0.30	0.70	0.00	0.00
	CPI3	Maize growers	0.58	0.42	0.00	0.00
Fuente Palmera *(Guadalquivir)*	FP1	Cotton growers	0.99	0.00	0.01	---
	FP2	Wheat growers	0.84	0.00	0.16	---
	FP3	Maize growers	0.96	0.00	0.04	---
	FP4	Groves growers	0.99	0.00	0.01	---

Source: WADI www.uco.es/grupos/wadi

The examples illustrated in the preceding table show variability in utility functions found by the MAUF elicitation technique, with the common feature of improving the predictive ability of models for each farm type.

An application of these models is the analysis of policy instruments. We have done this for the study of water pricing. A detailed analysis of all European case studies developed by the WADI project can be found in Berbel and Gutiérrez (2004).

In order to explain the main findings, we first comment as an example on the case study described by Gomez-Limon and Riesgo (2004), where the methodology proposed is applied to a single irrigated area in the Duero basin (Northern Spain) called ‘*Canal del Pisuerga*’ (9,300 ha). Figure 2 shows the three different curves developed for the clusters representing different farming types in this particular area.

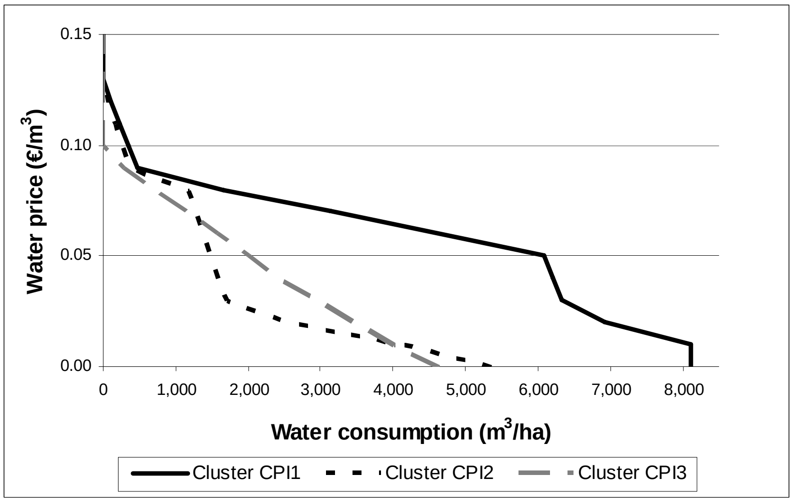

Figure #-2. Demand curves for three farm types inside an irrigated area

On the basis of these results, the authors conclude that the analysis of water pricing policy impacts clearly demonstrates that farmers display different behaviour patterns related to this natural resource. This diversity is shown by the different shapes of the demand curves for each of the clusters considered. The effects of irrigation water pricing thus vary significantly, depending on the group of farmers being considered.

By aggregating the cluster results in a particular irrigated area by using the percentage of their respective agricultural areas, we can obtain the aggregated demand for the whole irrigated area. In a further step, when we aggregate different irrigated areas within a basin or region demand curve, we obtain the simulated demand curve at basin/regional level. Figure 3 shows three examples in Europe of demand curves obtained using this methodology at aggregate level in three European river basins.

As we can see, there are large differences between basins, due to local natural conditions (soil, climate, etc.) and economic infrastructure (human resources, locational advantages, etc.), that limit farmers’ decision variables and sets of constraints, and thus determine water productivity and farmers' behaviour (shape of MAUFs).

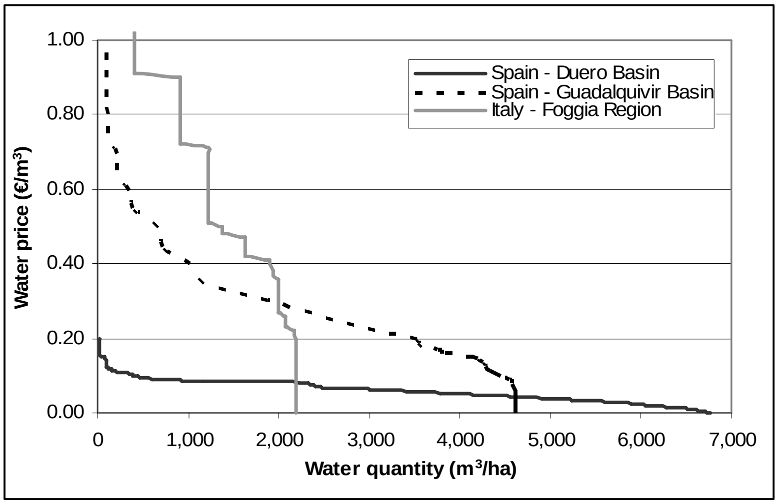

Figure #-3. Aggregated demand curves for irrigation in three European river basins

All the models were developed with the aim of deriving from farmers' production plans (crops and technology), the values of attributes that are of interest to policy-makers. These indicators used in connection with the MAUT models measure various impacts of water pricing at different level of aggregation: economic balance (farm income, farm contribution to GDP and public support), social impact (farm employment and seasonality), landscape and biodiversity issues (genetic diversity and soil cover), water use (water consumption and irrigation technology) and nutrient and pollutant balances (nitrogen balance, pesticide risk and energy balance). For an analysis of indicator definitions and the results obtained, readers are referred to Berbel and Gutiérrez (2004).

5.2 Water markets

The impact assessment of this water policy instrument from a multicriteria point of view is addressed in Arriaza *et al*. (2002). The authors examine an irrigated area of 54,000 hectares located in Southern Spain and elicit three multi-attribute utility functions, with farm size the classifying variable used to define farm types. Two criteria are regarded as simulating the farmers' response to policy changes: the maximisation of total gross margin (as a proxy for short-term profit) and the minimisation of risk (measured as the variance of the margins). The differences observed in the mathematical formulation of the utility functions support this approach to the problem by considering relatively homogeneous groups of farmers. The results achieved in this paper show that for most price levels (water availability situations), small and medium farmers buy water from large farmers, because of the higher utility of water for the smaller farmers. Furthermore, the simulation implemented demonstrates that the volume of traded water is very small in comparison with the total amount in the market, and is less than neo-classical theory would suggest.

Assuming that it is necessary to analyse farmers' decision-making within the MCDM paradigm, it is evident that water use (allocation to different crops and/or its transfer in the market) depends on the *utility* that this input offers them (contribution to MAUF value: attaining the various objectives that farmers try to simultaneously optimise), and not only on its *productivity* (profit generation). In this respect, we believe that water market modelling is more realistic when we assume that water reallocations move this resource from the uses that generates a relatively low level of utility towards those that generate greater utility, until an equilibrium point is reached at which the marginal utilities provided by water to all users equal the market price. This utilitarian approach assumes an extension of neo-classical theory, which assumes, as a particular case, that profit maximisation alone is taken into account as a unique management criterion, and that this defines market equilibrium when the value of the marginal product for all users is equal to the market price.

Dealing with public criteria achievement, the paper by Arriaza *et al*. (2002) considers only two indicators. First, in order to assess the whole economic impact of the introduction of local water markets, the variations in aggregated gross margin due to selling/buying water, as a proxy of economic efficiency, was selected. In this respect, the results obtained contradict the traditional assumption of higher expected farmers' income at aggregated level following the implementation of water markets. The results show that at certain price levels there is a reduction in the economic efficiency of the system. The second indicator implemented is the use of farm labour. Here, the results suggest that the social impact of water market implementation is very limited. In fact, the total increase in farm employment under the water market scenario is insignificant.

Gómez-Limón and Martínez (2005) take a further step in this methodology, simulating a spot market for irrigation water for a whole basin. The case study analysed in this paper is the Duero valley (78,000 km^2) in Northern Spain, where 555,582 hectares are dedicated to irrigated agriculture. In the basin, a total of 21 farms in seven irrigated areas were selected using to a cluster technique to capture the variability in farm types. Regarding the utility functions, three criteria were considered: maximization of total gross margin (TGM), minimization of risk (VAR) and minimization of the total labour input (TL).

In a further step towards the optimisation of an individual farm type, the authors propose a mathematical programming model that simulates the market equilibrium for different scenarios of water availability, transaction costs and water prices, quantifying for each case the socio-economic impacts considered as public criteria (economic efficiency and labour demand). On the basis of the results, some interesting practical conclusions can also be drawn, the most important of which is the potential of water markets to act as a demand policy instrument to improve economic efficiency and agricultural labour demand in this basin-scale framework, particularly in periods of water scarcity. The results achieved confirm this positive impact from the economic and social points of view. These gains are due to transfers being made to those producers with more highly commercial profiles (greater weight devoted to the TGM attribute), and who enjoy greater competitive advantages (favourable soil and climate conditions) and better geographic locations (downstream).

In any case, one of the key aspects of the previous works lies in the application of a methodology that improves the ability to simulate the farmers' response to policy changes, as validation procedures suggest. Therefore, the case studies discussed here represent an interesting approach to a better understanding and modelling of water markets in the real world.

5.3 Modernization of the irrigation infrastructure

Regarding the modernization of the irrigation infrastructure, Riesgo and Gómez-Limón (2002) propose a similar methodology to estimate the farmers' willingness to pay (WTP) for the new irrigation technology. Within this context, WTP embeds not only the productivity increases due to the implementation of the new technology, as neo-classical theory states, but also the increase in farmers' utility. This approach has been put into practice in an irrigated area of 9,392 hectares in Northern Spain (*Canal del Pisuerga*), with three relatively homogeneous groups obtained by cluster analysis, and group utility functions with four attributes: total gross margin, risk, farm labour and working capital.

Using the elicited utility functions, the authors obtain the water demand curves for each irrigation technology, and then the maximum farmers' WTP. For a WTP lower than the investment cost, the difference is considered as the minimum subsidy from the public sector that would be needed to adopt the new technology.

The study concludes that the WTP for water saving technologies is related to the shape of the farmers' MAUF, the technical efficiency of the technology and the water price. In particular, higher WTPs correspond to farmers who place greater weight on profit maximization. This result is consistent with an input valuation close to its marginal product value.

6. CONCLUDING REMARKS

Taking into account the evidence about how irrigators and policy-makers take their own decisions within a multi-criteria context (considering private and public criteria respectively), the first obvious conclusion is that any analysis focused on the management of irrigated agriculture ought to be developed within the MCDM paradigm.

This chapter has attempted to illustrate some aspects of the MCDM methodology as applied to the management of irrigated agriculture. The methodological approach proposed is initially descriptive, in that it tries to simulate farmers' responses to policy changes. For this purpose, in order to avoid aggregation biases, farmers are classified into homogeneous groups using cluster analysis, with the observed crop distribution being the classifying variable (proxies of farmers' utility functions). For each homogeneous group, a separate multi-attribute utility function is elicited on the basis of the weights that farmers attach to each individual objective. Next, once the objective functions have been fixed, the rest of the decision models (constraints sets) are built. Validations of the different empirical applications developed prove the worth of this modelling approach to simulating farmers' behaviour. In fact, we can affirm that the methodology proposed here improves the ability of traditional and other more recent MCDM models of simulating the farmers' responses to alternative policy instruments.

The low data requirement of this approach is also worth noticing: we need only the actual crop distribution and the mathematical formulation of each attribute with respect to the decision variables to develop these models. This is a critical point, because it allows the implementation of the methodology in the real word (excellent cost/benefit ratio: i.e. effort required/quality of results).

We have also proceed to the simulation of the new water and agricultural policy scenarios in order to obtain the impacts on each cluster, and then the aggregated impacts on the area of study from an economic, social and environmental perspective. Thus, this approach allows policy-makers' decision-making to be fed with quality data regarding the multiple effects of the instruments that may potentially be implemented. We believe this is also a useful feature of the methodology proposed, offering efficient selection of policy instruments.

Although the results of the empirical applications, as well as the validation of the models, are promising in the MCDM field, there are several aspects that should be further analysed in future studies. First, the use of additive and linear MAUFs is based on rather restrictive assumptions. Thus, new developments are needed that will permit us to use other separable and non-separable functions, in each case without losing the simplicity and the low data requirement features of the approach presented here. Secondly, in order to support policy-makers' decisions, public decision-making models should be developed. Only in this way can the 'governance' (transparency and public debate in public decision-making processes) of these agricultural systems be improved. Thirdly, the use of descriptive model predictions, as currently proposed, is limited to short-term analysis, since we are assuming static models (no structural changes in the farms). However, there are certain prospects of overcoming this limitation using multi-period and dynamic programming, which would allow for possible developments (technological changes, farm sizes, etc.) in irrigated areas. In this respect, the study of discounting criteria other than profit (non-monetary criteria) is still an open field for research.

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