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Water pricing: Analysis of differential impacts on heterogeneous farmers

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[1] European water policy requires all EU Member States to implement volumetric water pricing at rates that roughly cover the total costs of providing water services. The objective of this paper is to develop a methodology that will enable us to analyze the differential impact that a water pricing policy for irrigation would have on heterogeneous farmers of an irrigated area. For this purpose, multiattribute utility theory (MAUT) mathematical programming models were used. The methodology is implemented on a representative area in the Duero Valley in Spain. Our results show the usefulness of differential analysis in evaluating the impact of a water pricing policy. From them we observe significant differences in the evolution of agricultural incomes and estimate the cost recovery by the state, the demand for farm labor, and the consumption of agrochemicals resulting from the rise in water price between the various groups of farmers established within the analyzed irrigated area. *INDEX TERMS:* 6314 Policy Sciences: Demand estimation; 3210 Mathematical Geophysics: Modeling; 6324 Policy Sciences: Legislation and regulations; 6334 Policy Sciences: Regional planning; *KEYWORDS:* water pricing, irrigation water, Water Framework Directive, multicriteria programming, cluster analysis

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1. Introduction and Objectives

[2] The constantly rising demand for water in Spain clearly demonstrates the growing relative shortage of this resource. This has motivated an intensive polemic about the efficiency of use of this natural good by irrigated farms, which utilize 80% of the national water consumption [*Ministerio de Medio Ambiente*, 1998]. The apparently poor management of water in Spanish irrigated areas (large losses of water and its application to surplus crops, with low profitability and low labor demand) has served as an argument for the implementation of demand water policies as an indispensable solution to this problem. Such demand policies consist in the main of the public reallocation of water resources, water pricing, the promotion of infrastructure improvements and the introduction of water markets [*Chakravorty and Zilberman*, 2000; *Dinar et al.*, 1997; *Easter and Hearne*, 1995; *Sumpsi et al.*, 1998].

[3] The water economy has matured not only in Spain, but also in other Member States of the European Union (EU). This situation has caused EU institutions to decide to develop a common policy in the field of water management. One result of this interest has been the recent approval of the Directive 2000/60/CE of the European Parliament and of the Council, which established a framework for Community action in the field of water policy (the Water Framework Directive, or WFD). There is no doubt that one of the most divisive topics of this directive is the article related to water pricing (article 9), that has been proposed as the main policy for dealing with demand for water within the EU.

[4] The European WFD establishes the convenience of using water pricing as the economic instrument to achieve the proposed environmental objectives. In this sense, article 9 establishes that "Member States shall take account of the principle of recovery of the costs of water services, including environmental and resource costs." Nevertheless, the normative adds that "Member States may in doing so have regards to the social, environmental and economic effects of the recovery as well as the geographic and climatic conditions of the region or regions affected." This final text of the article related to water pricing is much less tough than the one proposed in the first drafts of the WFD, which pursued the compulsory implementation of the water full cost recovery (FCR) principle. In fact, the approved article only requires the introduction before 2010 of the necessary water pricing measures in order to "provide adequate incentives for users to use water resources efficiently, and thereby contribute to the environmental objectives of this Directive."

[5] Although water pricing established by the European WFD is basically due to environmental demands, the reasoning on which this instrument is based is purely economic. In this sense, farmers in irrigated areas, according to economic theory, would respond to the introduction of (or

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an increase in) water prices by reducing their consumption, in accordance with a negatively sloped demand curve. In this way the water savings obtained would be redistributed among other uses such as productive or environmental purposes (ecological flows in rivers, etc.), according to the preferences of society. Such a reallocation of water resources would improve the efficiency of their use.

[6] However, this set of assumptions, made from the point of view of neoclassical economic theory, has been disputed by various authors, who have studied the impact of water pricing on specific irrigated areas. In the case of Spain, we may mention the works of *Varela-Ortega et al.* [1998], *Gómez-Limón and Berbel* [1999], and *Feijoó et al.* [2000]. These studies have all demonstrated that water pricing would not stimulate the desired changes in water use (reduced consumption and reallocation of the water saved), due to the low elasticity of demand for irrigation water. Furthermore, the implementation of this economic instrument would produce collateral effects, such as a decrease in agricultural income and a reduction in the demand for agricultural labor. These conclusions could be generalized to other countries and regions, both within and outside the EU, where irrigated agriculture is a strategic sector in rural areas. The above comments show the importance of water pricing policies for the future of irrigation since, presumably, they would have a negative influence on its competitiveness and thus for the future of the rural areas in which it is employed.

[7] This study tries to establish a methodology for the analysis of the potential impact of the implementation of water pricing on irrigated agriculture, studying its economic, social and environmental effects. For this purpose, we carried out a simulation technique based on mathematical programming under the multicriteria decision making (MCDM) paradigm. The methodological proposal outlined here is also based on a careful classification (aggregation) of farmers, in order to enable the differential impacts of water pricing by farm types (homogeneous groups of farmers) to be analyzed.

[8] Finally, the study attempts to apply the proposed methodology to a particular irrigated area (community of irrigators of *Virgen del Aviso* channel, Spain), analyzing the impact of the hypothetical implementation of recovery of costs water pricing proposed by the WFD on each of these groups of farmers.

2. Methodology

2.1. Key Elements

[9] Before the proposed methodology can be discussed, a brief presentation of the elements on which it is based is required: i.e., the classification (aggregation) of farmers into homogeneous groups and the scenarios proposed for the WFD implementation.

2.1.1. Aggregation Bias and Cluster Analysis

[10] Modeling agricultural systems at any level other than that of the individual farm implies problems of aggregation bias. In fact, the introduction of a set of farms in a unique programming model overestimates the mobility of resources among the 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 always upwardly biased and the values obtained for decision variables tend to be unachievable in real life [*Hazell and Norton*, 1986, p. 145].

[11] This aggregation bias can only be avoided if the farms included in the models fulfill strict 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).

[12] The case studied here is an irrigated area of about 1902 has (community of irrigators of *Virgen del Aviso* channel). This is a small area that can be regarded as fairly homogeneous in terms of soil quality and climate, and where the same range of crops can be cultivated and have similar yields. Furthermore, the whole set of farms that are integrated in this agricultural system operates the same technology at a similar level of mechanization. Given these conditions, it can be assumed that the requirements regarding technological homogeneity and pecuniary proportionality are basically fulfilled.

[13] In view of the existence of efficient capital and labor markets, the constraints included in modeling this system have been limited to the agronomic requirements (crop rotations) and the restrictions imposed by the Common Agricultural Policy (set aside land and sugar beet quotas) that are similar for all farms. The requirement of institutional proportionality may thus also be regarded as having been met.

[14] We can thus see that agricultural systems of this kind can be modeled by means of a unique linear program with relatively small problems of aggregation bias. For this reason a good number of studies with similar units of analysis have been based on this kind of aggregate model [e.g., *Bernard et al.*, 1988; *Chaudhry and Young*, 1989; *Kulshreshtha and Tewari*, 1991; *Varela-Ortega et al.*, 1998; *Berbel and Gómez-Limón*, 1999].

[15] However, it is essential to note that the requirements discussed above are outlined from the point of view of neoclassical economic theory, which assumes that the sole criterion on which decisions are based is profit maximization. If a multicriteria perspective is being considered, an additional homogeneity requirement emerges in order to avoid aggregation bias; namely, homogeneity related to choice criteria. This kind of similarity has been implicitly assumed in studies based on a unique multicriteria model for the whole set of farmers in the area being analyzed [e.g., *Gómez-Limón and Berbel*, 1999].

[16] Nevertheless, the experience that has been accumulated in this field leads us to suspect that the decision criteria of farmer homogeneity do not reflect the normal situation in real agricultural systems. This suspicion, as will be commented, has been confirmed by a survey of the area analyzed. In fact, the decision criteria are primarily based on psychological characteristics of the 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 their objective functions (in which the weightings given to different criteria are

condensed), rather than other differences related to the profits of economic activities or disparities in resources requirements or endowments.

[17] In order to avoid aggregation bias resulting from lumping together farmers with significantly different objective functions, a classification of all farmers into homogeneous groups with similar decision-making behavior (objective functions) is required. For this issue we have taken the work of *Berbel and Rodríguez* [1998] as a starting point. These authors noted that for this type of classification the most efficient method is cluster analysis, taking farmers' real decision-making vectors (actual crop mix) as the classification criterion.

[18] The term "cluster analysis" embraces a loosely structured body of algorithms, which are used in the exploration of data from the measurement of a number of characteristics for a collection of individuals. Cluster analysis is concerned with the discovery of the groups. The word "cluster" or "group" should be interpreted as a collection of "similar" objects. In our case, the collection of individuals is the farmers operating in a particular irrigated area.

[19] In order to obtain homogeneous groups with similar decision-making behavior, the cluster analysis should be performed using the relative importance of the different management criteria regarded by farmers as classification variables. Unfortunately, as shown by *Berbel and Rodríguez* [1998], these data, obtained through verbal questioning, only poorly represent the real weightings that are taken into account by farmers. This may be because management criteria are not well understood by farmers. *Deffontaines and Petit* [1985] agree with these authors when they claim that farmers' criteria are better observed by indirect methods than by direct questioning. Thus the sample of farmers needs to be grouped according to variables that can be regarded as proxies of the relative importance of management criteria.

[20] As pointed out above, we can assume that in a homogeneous area the differences in the crop mix among farmers are mainly caused by their different management criteria (utility functions) rather than by other constraints such as land quality, capital, labor or water availability. Thus the surface (in percentage) devoted to the different crops (proxies of the real criteria) can be used as classification variables to group farmers using the cluster technique, as required for our purposes.

[21] In this sense, it is also important to note that the homogeneous groups obtained in this way can be regarded as "fixed" in the medium and long run. As noted above, the decision criteria are based on psychological features of the decision makers, which is why they may be regarded as producers' structural characteristics. In fact, 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 irrespective of any change in the policy framework (i.e., water pricing). In other words, once the homogeneous groups of producers have been defined for actual data (crop mix), we can assume that all elements inside each group will behave in a particular way when the policy variables change; that is, crop mix decisions will be modified in a similar fashion by all farmers within a cluster, although such modifications would differ among the individual groups defined.

[22] For a more concrete definition of the cluster analysis performed in this research, we may also note that the classification of farmers was done by considering the following parameters: (1) measurement of distances, chi-square distance among actual crop mixes, expressed in percentages, and (2) aggregation criterion, Ward's method (minimum variance). For more detailed information about this statistical technique, see *Chatfield and Collins* [1980] or *Hair et al.* [1998].

2.1.2. Implementation of the WFD: Scenario Proposals

[23] Alike in many countries, Spanish irrigation water users currently pay to the State a price that only partially reflects the cost of providing water. In fact, only the operational and management costs are covered by this tariff. The remaining financial costs (i.e., capital depreciation) are met by the national budget and form a hidden subsidy to users, especially in the agricultural sector.

[24] The first practical problem that we encountered in establishing appropriate scenarios is the lack of information regarding the real cost of irrigation water that should be used by each member state to implement the WFD. As far as Spain is concerned, only a few studies have been carried out, giving results that range from 0.01 to 0.11 €/m^3. Probably the most reliable analysis is that of *Escartín and Santafé* [1999] which estimates the financial water costs for irrigation of different Spanish basins. For the Duero basin (where the area under analysis is included), the estimated total cost for irrigated water was 0.041 €/m^3.

[25] We therefore selected three water-pricing scenarios for our case study. First is "medium" price. Considering Escartín and Santafé estimate, a price of 0.04 €/m^3 may be regarded as a "fair" value for cost recovery, which would at least cover the financial costs. Second is "subsidized" price. This considers a price of 0.02 €/m^3. This price will not be capable, in any case, of recovering total costs, but might at least serve as an economic instrument to encourage a more efficient resource use. Third is "FCR" price. A price of 0.06 €/m^3 would be a tough application of full cost recovery principle, including a provision for environmental costs. This tariff has been estimated assuming that the environmental costs account for 50% of the financial costs. Yet we stress the hypothetical consideration of this scenario since a more precise tariff would imply a more detailed study, far beyond the scope of this study.

2.2. Methodology Outline

[26] On the basis of the key elements identified above, the methodology adopted by this study can be graphically displayed as in Figure 1. According to this plan, the proposed methodology can be divided into four principal stages, as outlined below.

[27] The first stage differentiates among the different groups of irrigators to be analyzed. These groups, as has been observed, should be sufficiently homogeneous in their decision-making behavior (weighting of the objectives considered) to allow aggregate models to be constructed and resolved without unwanted bias. This classification of farmers was performed by the cluster analysis referred to above.

[28] Once homogeneous groups of farmers have been defined, the second stage builds the mathematical models. For each cluster a different multicriteria model was devel-

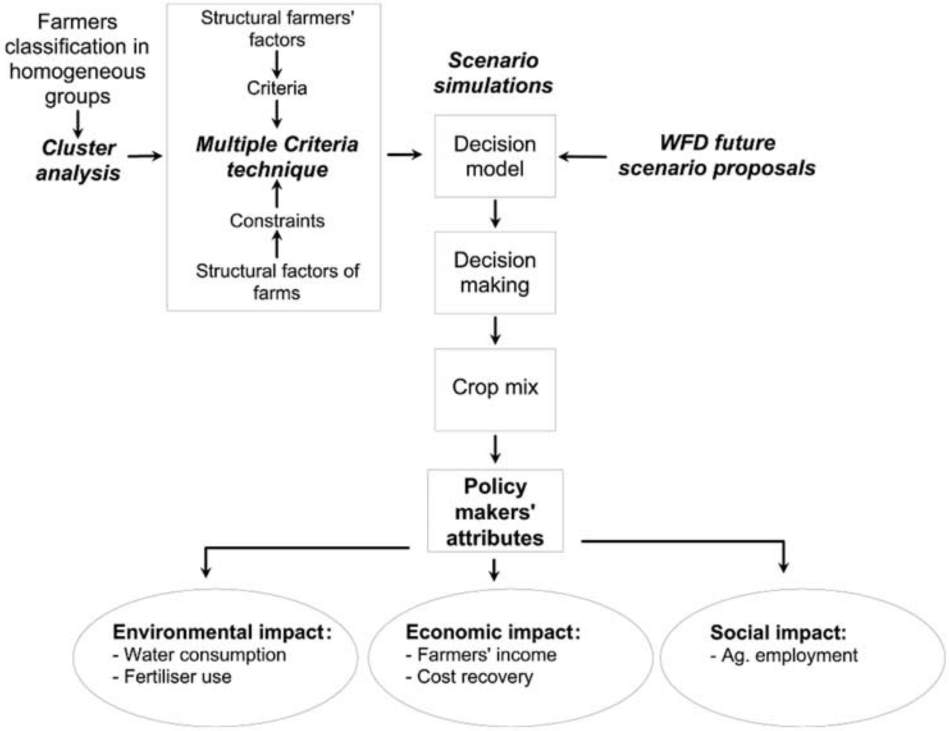

Figure 1. Research methodology.

oped, in order to allow independent simulations based on the decision-making behavior 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, have to be outlined. Thus, 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.

[29] The classification criterion used in the cluster analysis allows us to assume that all the farmers in the various groups are homogeneous in the way in which they consider the objectives that they wish to achieve. In other words, a unique utility function as an objective function in their decision making can characterize the set of farmers that makes up each cluster. The estimate of this utility function for each cluster will be made using the multicriteria procedure that is described in section 2.3.

[30] Estimates of the respective utility functions were obtained by models fed with data gathered for the current situation (highly subsidized water price per unit of irrigated surface). Here it is important to note that 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 the medium and long run. 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 need to face.

[31] With regard to the constraints that need to be satisfied in the decision-making process, it is worth mentioning that these are mainly due to the structural characteristics of the farms (climate, soil fertility, market limits, European Common Agricultural Policy (CAP) requirements, etc.), that are basically identical for all of them. Only slight differences have been fixed by clusters according to the data obtained in the survey; these are mainly related to farm type area and sugar beet quotas.

[32] The third stage of the study performs the simulations. Thus departing from the WFD implementation scenarios already explained, the decisions taken, i.e., crop mixes and irrigation technologies, by the clusters of irrigators were obtained in the different cases.

[33] From the crop mixes obtained in the model simulations we analyze certain attributes to measure the impacts of the policy instrument. These are indicators relevant to policy makers from an economic (farmers' income and the state's recovery of costs), social (direct employment generated in the agricultural sector) and environmental (water consumption and fertilizer consumption) point of view. The calculation of these attributes and the analysis of the efficiency of the economic instrument (water pricing) proposed will be the core of the fourth stage of our methodology.

2.3. Multicriteria Programming Approach

[34] As opposed to the neoclassical approach, we have assumed that not only profit determines the level of farmer's utility, but that other attributes such as risk, leisure time, management complexity, etc., are also involved in farmers' decision making. For discussions of MCDM techniques in agriculture, see *Anderson et al.* [1977], *Hazell and Norton* [1986], and *Romero and Rehman* [1989].

[35] Taking into account the evidence about how farmers take their decisions while trying to simultaneously optimize a range of conflicting objectives, we have proposed multi-

attribute utility theory (MAUT) as the theoretical framework for the MCDM programming modeling technique to be implemented. MAUT, particularly developed by *Keeney and Raiffa* [1976], has often been argued to have the soundest theoretical structure of all multicriteria techniques [*Ballestero and Romero*, 1998]. At the same time, from a practical point of view, the elicitation of utility functions has presented many difficulties. In this paper, we have followed a methodology that tries to overcome these limitations assuming some reasonable simplifications.

[36] 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. Thus the utilities of n attributes from different alternatives are captured in a quantitative way via a utility function, mathematically, $U = U(x_1, x_2, \ldots, x_n)$, where U is the multiattribute utility function (MAUF) and x_i are the attributes regarded by the decision maker as relevant in the decision-making process.

[37] If the attributes are mutually utility-independent the formulation becomes separable: $U = f\{u_1(x_1), u_2(x_2), \ldots, u_n(x_n)\}$. In modeling the agricultural sector, among the family of separable utility functions, additive functions has often been adopted. This study has also opted to follow this approach, and bases its analysis on mathematical models using an additive MAUF as the objective function. These MAUFs take the following mathematical form:

$$U_j = \sum_{i=1}^{n} w_i u_i(r_j), \qquad i = 1, \ldots, m \tag{1}$$

where U_j is the utility value of alternative j, w_i is the weight of attribute i and $u_i(r_j)$ is the value of the additive utility due to attribute i for the alternative j.

[38] Considering an additive MAUF, alternatives are ranked by adding contributions from each attribute. Since attributes are measured in terms of different units, normalization is required to enable them to be added. The weighting of each attribute expresses its relative importance.

[39] Although the additive utility function represents a simplification of the true utility function, the mathematical form, *Edwards* [1977], *Farmer* [1987], *Huirne and Hardaker* [1998], and *Amador et al.* [1998] have shown that the additive function yields extremely close approximations to the hypothetical true function even when the conditions of utility independence are not satisfied [*Fishburn*, 1982; *Hardaker et al.*, 1997]. As *Hwang and Yoon* [1981, p. 103] point out, "theory, simulation computations, and experience all suggest that the additive method yields extremely close approximations to very much more complicated nonlinear forms, while remaining far easier to use and understand."

[40] Having justified the use of the additive utility function, we take the further step of assuming that the individual attribute utility functions are linear. Hence the expression (1) becomes its simplest mathematical form:

$$U_j = \sum_{i=1}^{n} w_i r_{ij}, \qquad i = 1, \ldots, m \tag{2}$$

where r_{ij} is the value of attribute i for alternative j.

[41] This formulation implies linear utility-indifferent curves, 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]. We therefore adopt this simplification in the elicitation of the additive utility function.

[42] Finally, it is worth mentioning that furthermore the theoretical advantages of this approach explained above, the additive linear utility specification used in this paper has been chosen based on comparison with other specifications, as explained by *Arriaza and Gómez-Limón* [2003].

2.4. MAUF Elicitation Technique

[43] Having agreed to use additive linear utility functions, the ability to simulate real decision makers' preferences is based on estimating relative weightings. We have selected a methodology that avoids the necessity of an interacting process 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 and has previously been used by *Berbel and Rodríguez* [1998], *Gómez-Limón and Berbel* [1999], *Arriaza et al.* [2002], and *Gómez-Limón et al.* [2002].

[44] In order to avoid unnecessary repetition, we refer to the papers mentioned above for details of all aspects of this multicriteria technique. Here we wish only to point out that the results obtained by this technique are the determination of the weighting of objectives (w_i) that imply utility functions that are capable of reproducing farmers' behavior as actually observed. As *Dyer* [1977] demonstrated, the weights obtained are consistent with the following separable and additive utility functions:

$$U = \sum_{i=1}^{q} \frac{w_i}{k_i} f_i(x) \tag{3}$$

where k_i is a normalizing factor.

[45] Precisely because this utility surrogate needs to fulfill the requirements of being an additive MAUFs, it must range between 0 and 1. For this reason, the following equivalent MAUF expression is used:

$$U = \sum_{i=1}^{n} w_j \frac{f_i(x) - f_{i*}}{f_i^* - f_{i*}} \tag{4}$$

The normalizing factor in (4) is thus the difference between the maximum (f_i^*) and minimum (f_{i*}) values for objective i in the payoff matrix developed for the criteria considered.

[46] The proposed method thus provides utility functions that can be used as an instrument to simulate the observed behavior of farmers. In this connection it is worth mentioning that this technique was used several times, once for every cluster defined, in order to obtain the characteristic MAUF of each of them.

2.5. Scenario Simulations

[47] In order to simulate the various pricing scenarios we decided to estimate different water demand functions in the

case study area; one for each cluster. This enables us to analyze the impact of the tariffs being considered as scenarios for the implementation of the WFD for each group of farmers.

[48] The demand curves are the result of the irrigators' production adjustments in the face of rising water prices. In order to account for the new scenarios, the simulation models included the following new alternatives: (1) substitution of water-intensive crops by others with less need for water, (2) cessation of irrigation and introduction of rain-fed crops, and (3) introduction of new irrigation technologies.

[49] Although the implementation of water stressing (deficit irrigation) is in theory one way of dealing with higher water tariffs, it has not been considered since it is not a real alternative for farmers, as was shown by the survey. So, when the price of irrigation water is raised, farmers will opt for less water-intensive or simply rain-fed crops in preference to implementing deficit irrigation. Identical responses have been found in other empirical studies [*Sunding et al.*, 1997; *Schuck and Green*, 2001]. This behavior is mainly the result of the low elasticity of irrigation water production functions [*Nieswiadomy*, 1988; *Ogg and Gollehon*, 1989].

[50] In sum, the presented simulations are based on "static long-run analysis", this is, models that estimate farmers' decision making after the adjustment strategies have been implemented. Considering that introduction of new irrigation technologies could take some years, our predictions would apply to a time period of 3–5 years.

[51] Furthermore, this simulation exercise assumes that the only changing variable is water price. Therefore any other policy (i.e., Common Agricultural Policy: subsidies, agricultural prices, etc.) or key factor (farming costs, technological availability, etc.) are considered the same in our future scenario.

[52] Generating demand curves in accordance with the above considerations required corresponding simulation models to be built. These models are similar to those that enabled us to obtain the payoff matrices, but they take the following considerations into account: (1) The objective functions (to be maximized) were the utility functions obtained for each cluster. (2) New activities (crop irrigation technology "double" variables) are introduced in order to allow changes in the irrigation techniques and the inclusion of rain-fed crops. (3) In the calculation of gross margins of each crop (GM_i) the water cost generated by the different tariffs has been included. The gross margins considered are thus equal to the initial gross margins (with zero volumetric tariff) less the amount paid for water (water consumption for each crop multiplied by the tariffs) for each water price.

[53] Once the models have been built, the method of simulating farmers' behavior as a reaction to the water pricing policy consists of parameterizing the water price, starting with a tariff of 0 €/m^3. This tariff was increased progressively, being incorporated as a variable cost for the different crops according to their respective water needs. For each tariff it is possible to determine the crop mixes that would probably be planned by farmers, which enables us to calculate water consumption (demand curve for irrigation water) and the values of other attributes of interest to the analyst, as is demonstrated in section 2.6.

2.6. Policy Makers' Attributes

[54] The attributes are values of interest to the analyst that are deduced from the vectors of decision variables (crop plans) chosen by the agricultural producers. The models were developed in order to obtain, at the same time as the crop plan, the values reached by the different attributes that are of interest to policy makers. Nevertheless, it should be noted that these attributes are not relevant to the farmers' decision-making process, but are merely outputs of the models that were not utilized as criteria in the objective functions.

[55] The policy makers' attributes considered here attempt to analyze the kind of impacts that implementation of the WFD might have on irrigated areas: (1) First is economic impact, which is measured in our model by the gross margin (farm revenue estimator) and by the public sector revenue derived from irrigation water payments, both attributes measured in €/ha. (2) Second is social impact. Agriculture is the main source of employment in most irrigated areas in continental Spain. This means that any change in irrigation water pricing policy could affect the social structure of these regions. This phenomenon can be evaluated via the labor demand attribute, which is measured in labor day per ha. (3) Last is environmental impact. Estimated water consumption is one of the attributes that policy makers try to control. Its incorporation as a relevant attribute is of interest in analyzing the amount of water saved in agriculture as a result of the implementation of the WFD. Another environmental effect of growing relevance is the nonpoint source pollution caused by the use of agrochemicals in agriculture. Because of this, the nitrogen balance (nitrogen applications minus nitrogen withdrawals, measured in kg of nitrogen per ha) can also be regarded as an indicator of the environmental impact of agricultural activities that could be modified by the WFD pricing policy.

3. Case Study

3.1. Description of Area

[56] The evaluation of the impact of water pricing needs to be developed in the context of real agricultural systems. Thus the practical application of the methodology proposed above will be based on the community of irrigators of *Virgen del Aviso* channel in northern Spain.

[57] This irrigated area covers 1902 ha, on which about 820 irrigators are farming. The range of crops in 2000, a typical year, included maize (54.8%), winter cereals such as wheat and barley (8.3%), alfalfa (3.5%), sugar beet (5.0%), sunflower (6.5%), set aside (16.6%), and other minor crops (5.3%).

[58] The most widely used irrigation system is gravity irrigation, while sprinkler irrigation is used only for sugar beet. The official water allotment is 8021 m^3/ha per year, but on average only 4218 m^3/ha per year is actually consumed.

[59] Water pricing is currently based on a fixed sum per unit of irrigated surface, like most irrigated areas in Spain. In this case the water tariff is 139.50 €/ha, equivalent to a volumetric tariff of 0.017 €/m^3.

Table 1. Clusters of Farmers in the Irrigated Area Virgen del Aviso[a]

	Cluster 1 Commercial Farmers	Cluster 2 Risk Diversification Farmers	Cluster 3 Conservative Farmers	Average Farmer in Irrigated Area
Share of farmers	45.5%	24.2%	30.3%	
Share of surface	23.2%	33.4%	43.4%	
Average age	47.9	44.9	47.1	46.9
Share of income from agriculture	76.5%	88.1%	89.0%	83.1
Educational level	primary, 63.3%; without education, 23.3%	primary, 68.8%; secondary, 25%	primary, 60.0%; secondary, 35.0%	primary, 63.6% secondary, 22.7%
Agricultural training	agricultural courses, 86.7%	agricultural courses, 87.5%,	agricultural courses, 55.0%; without training, 35.0%	agricultural courses, 77.3%
Agricultural information sources	farmers' unions, 83.3%	farmers' unions, 93.8%	farmers' unions, 65.0%	farmers' unions, 80.3%
Employees	no, 86.7%	no, 87.5%	no, 75.0%	no, 83.3%
Total surface, ha	21.8	73.1	87.0	54.0
Irrigated surface, ha	19.2	51.8	53.7	37.5
Crops				
Winter cereals	8.7%	35.8%	42.7%	32.5%
Maize	70.7%	38.3%	15.1%	35.7%
Sugar beet	7.8%	12.7%	4.1%	7.9%
Sunflower	2.3%	0.6%	0.5%	0.9%
Alfalfa	2.3%	4.3%	17.0%	9.3%
Others	0.6%	0.6%	0%	1.0%
Set aside	5.0%	7.7%	20.5%	12.6%

[a]Source: Own survey.

[60] The selection of this agricultural system as the case study is due to its specific characteristics, in that it can be regarded as an "average" irrigated area in the Duero basin. Other practical reasons, such as the availability of good quality data, were also taken into account.

[61] All the data required for feeding the models were obtained both from official statistics and from a survey developed in the irrigated area studied. This survey was carried out during 2000–2001 agricultural year for a sample of 66 farmers selected in a random process.

[62] The survey was based on a questionnaire where individual information (particular data for each farmer) was collected focusing on the following aspects: (1) The first aspect is variables related with agricultural production, such as the surfaces devoted to each crop, yields obtained, fixed and variable costs by crop, irrigation water volume, and number of irrigation events for each crop, etc. Other variables dealing with the constraints that limit the crop mix (sugar beet quotas, rotational constraints, etc.) were also included. (2) The second aspect is socioeconomic variables. Among these variables were included the farmer's age, family size, educational level, total income (from farming and nonfarming activities), amount of land owned and leased, etc. (3) The third aspect is variables related with management criteria, as structural variables for the purpose of better understanding of the farmer's behavior. In this sense, farmers were asked about their basic management criteria (profit maximization, maximization of leisure, minimization of risk, etc.), in order to propose the objectives a priori taken into account by the producers for their use in the MAUF elicitation methodology. The questionnaire and the main results of the survey are available from the authors on request.

3.2. Cluster Analysis

[63] Following the cluster technique proposed in 2.1.1, we obtained three homogeneous groups. The characterization of these clusters is shown in detail in Table 1. Some aspects can be outlined.

[64] 1. Cluster 1, the first group, included the largest percentage of farmers (45.5%) but represented the smallest proportion of the surface of the irrigated area (23.2%). These farmers, unlike the other groups, were not exclusively engaged in agriculture. They managed small-irrigated farms (19.2 ha on average), mostly sown with maize (71%) and sugar beet (8%). These are the most lucrative crops the farmers can choose, but are also the most risky. This feature led us to denominate this group as "commercial farmers."

[65] 2. Cluster 2, the second group, had the smallest proportion of farmers (24.2%), who farmed 33.4% of the area under study. Its profile was characterized by farmers with large irrigated farms (51.4 ha), which they ran on a full-time basis. The crop mix mainly consisted of maize (38%), winter cereals (36%) and sugar beet (13%). We therefore regard this group as "risk-diversifying farmers."

[66] 3. Cluster 3, the third group, consisted of 30.3% of the farmers and included the largest proportion of the irrigated area (43.4%). This cluster managed large irrigated farms (53.7 ha), whose farmers had in agriculture their principal activity. Their land was mostly given over to winter cereals (43%) and sunflower (17%), which are less profitable but less risky than other crops, and to maize (15%). These features led us to label this group "conservative farmers."

3.3. Multicriteria Modeling

[67] Each mathematical model includes a set of "decision variables" that controls the simulation procedure and determines the feasible decision-making process; e.g., the farmer himself can determine his/her crop distribution and select the most appropriate irrigation technology. This decision making as expressed through the decision variables is focused in such a way as to achieve the various objectives that are taken into account by the decision maker, being limited by certain constraints that have to be fulfilled. These are the main

Table 2. Decision Variables

Crop C_i	Irrigation Technique T_j	Variables C_i-T_j
Wheat (WHE)	Furrow (FUR)	WHE-FUR, WHE-SPR, WHE-RAF
Barley (BAR)	Sprinkler (SPR)	BAR-FUR, BAR-SPR, BAR-RAF
Maize (MAI)	Rain-fed (RAF)	MAI-FUR, MAI-SPR
Sugar beet (SUB)		SUB-SPR
Sunflower (SUN)		SUN-FUR, SUN-SPR, SUN-RAF
Alfalfa (ALF)		ALF-FUR, ALF-SPR, ALF-RAF
Potatoes (POT)		POT-FUR, POT-SPR
Beans (BEA)		BEA-FUR, BEA-SPR

elements of the model that is described below for this particular study.

3.3.1. Decision Variables

[68] Each cluster of farmers has a set of variables C_i-T_j, representing the binomial crop irrigation technology. These are the decision variables that may take any value included within the feasible set, and they have to be positive. A total of 19 variables have been considered, as Table 2 shows.

3.3.2. Objectives

[69] After a survey of the study area, we concluded that farmers choose a crop distribution that takes the following objectives into account: (1) Maximization of total gross margin (TGM), as a proxy of profit, is obtained from the average crop gross margins from a time series of seven years (1993/1994 to 1999/2000) in constant 2000 euros. (2) Minimization of risk (VAR) is an important factor in agricultural production. Farmers have a marked aversion to risk, so the model should include this objective. In this case risk was measured as the variance of the TGM (VAR), following the classical *Markowitz* [1952] approach. The risk is thus computed as $\vec{X}'\cdot[\mathrm{Cov}]\cdot\vec{X}$, where [Cov] is the variance-covariance matrix of the crop gross margins during the 7-year period, and $\vec{X}$ is the crop decision vector. (3) The minimization of total labor input (TL) 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 (labor-intensive crops require more technical supervision). (4) Minimization of working capital (K) has the aim of reducing the level of indebtedness. In order to model this objective we divided the year into months, differentiating in this way the periods of cropping activities (capital immobilization) and sales (income).

[70] These objectives, which are selected a priori, were analyzed for the different clusters in accordance with the methodology described above. This analysis enables us to assess the importance of each objective in the decision-making process for each homogeneous group of farmers.

[71] In this way, TGM, VAR, TL and K will be the attributes that would be included as arguments in the MAUFs of the individual clusters of farmers. In any case, it is convenient to point out that these attributes are the most relevant ones as revealed through the questionnaire, but is not improbable that additional attributes might be able to explain the real behavior of farmers more accurately. In any case, we consider that MAUFs, including the attributes proposed above, are adequate to model farmers' decision-making processes (see section 4.2), giving better results than assuming profit maximization behavior through the classic PL and its variants.

3.3.3. Constraints

[72] We identify the following constraints within the model as applied to each group of farmers. (1) First is land constraint. The sum of all crops must be equal to the total surface available to the farm type of each cluster. (2) Second is CAP constraints. We included 5% of set aside for cereal, oilseed and protein crop (COPs). Sugar beet, because of the quota, is limited in each cluster to the maximum area in the period studied. (3) Third is Rotational constraints. These were taken into account according to the criteria revealed for the farmers in the survey. (4) Fourth is market constraints. We decided to limit alfalfa area to the maximum in the period 1993–1999 because of its rigid demand. This crop is exclusively consumed by the regional flocks of dairy cows and sheep, whose sizes are fairly constant, due to CAP quotas, making it unlikely that alfalfa production sold could be higher than the maximum proposed.

[73] This basic model described above was built separately for each of the clusters under analysis. In these models the objectives considered a priori were the same for all groups of farmers. On the other hand, the constraints were altered depending on the clusters analyzed, taking their particular circumstances into account, for example, in the case of the total farm surface, which was adjusted for each of the clusters considered. Thus, for cluster 1 the available farmland was 18.5 ha, for cluster 2 it was 51.4 ha, etc. The same applies to the sugar beet quota and market limitations.

4. Results

4.1. Objective Weighting and Utility Function Elicitation

[74] Once the basic models had been built for each cluster, they were soptimized successively for the individual objectives proposed: TGM maximization and VAR, TL and K minimization, thus obtaining the payoff matrices for each group of farmers. The next step in the procedure is to identify the objectives that participate in the decision-making process and the weight attached to each one by each homogeneous group of farmers. Finally, we elicit the MAUFs considered by each cluster, as it is shown in Table 3.

4.2. Model Validation

[75] Validation of the models built for each group of farmers is a key aspect of testing the quality of the results.

Table 3. MAUFs Elicitation

Cluster	W_1 (TGM)	W_2 (VAR)	W_3 (MOT)	W_4 (K)	Normalized Utility Function
Cluster 1: Commercial farmers	78.4%	0.0%	0.0%	21.6%	$U = 35.2\ TGM - 23.2\ K$
Cluster 2: Risk-diversifying farmers	32.0%	0.0%	0.0%	68.0%	$U = 14.8\ TGM - 72.49\ K$
Cluster 3: Conservative farmers	19.0%	3.6%	0.0%	77.4%	$U = 9.7\ TGM - 3.7\ VAR - 86.6\ K$

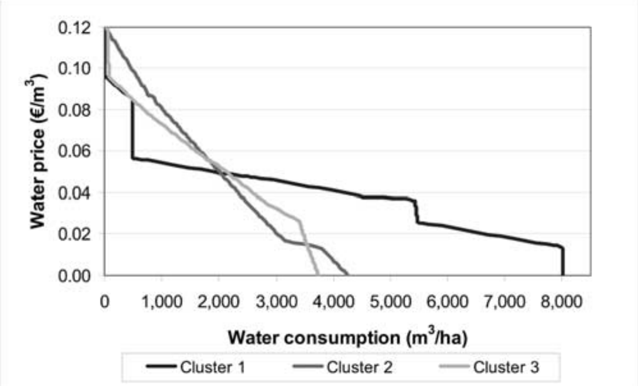

Figure 2. Irrigation water demand curves.

The procedure employed was to compare the real situation (observed) with the data simulated by the models for the current scenario. This type of comparison is the most common method of validating models [*Qureshi et al.*, 1999]. Implementing this technique demonstrated that the deviations in the objectives and the decision variable spaces were sufficiently small to permit us to regard the model as a good approximation to the actual decision-making process in all clusters.

4.3. Water Demand Functions

[76] The simulations described above gave us the demand curves for irrigation water; one for each cluster of farmers considered in the case study area (see Figure 2). The most noticeable differences between the curves in the Figure 2 are the water tariff that is currently being paid in this area (zero marginal cost, and therefore price equivalent to 0 €/m^3) and the range of prices being considered for future pricing scenarios, the quantity of water demanded varies significantly from cluster to cluster. Thus, with the current tariff, cluster 1 consume 8021 m^3 per ha (legal limit for water demand in this irrigated area), a substantially higher volume than clusters 2 and 3, whose water consumption are 4258 and 3743 m^3/ha, respectively. Nevertheless, as can be seen, these patterns of consumption will vary along the demand curves as a result of increases in the water price.

[77] As pointed out above, current water consumption by the clusters 2 and 3 are considerably lower than the endowment given to this irrigated area (8021 m^3/ha). This is due to the minimizing working capital and risk aversion behavior that characterizes these groups of farmers. Their crop plans thus emphasize “cheap” (with lower working capital needs) and “safe” (with lower TGM variability) crops, which correspond to those that have lower water requirements, such as winter cereals and sunflower.

[78] It is also worth pointing out that changes in water demand in the different clusters can be justified by the existence of segments with different slopes for each price interval (i.e., elasticities of demand) that can be distinguished within each group’s demand curve. In all cases, the segments of the water demand curves with high slopes (relative low elasticities) coincide with prices for which the farmers are insensitive to resource price increases, maintaining their usual crop mixes and irrigation techniques without any substantial change. On the other hand, the segments with lower slopes (relative high elasticities) correspond to those water tariffs that encourage farmers to replace their current crops with others with lower water requirements and/or to improve their irrigation systems (water use efficiency) by adoption sprinkler techniques.

[79] The analysis of the water demand curves suggests differences in the behavior patterns displayed by farmers in a particular irrigated area. This fact has not been taken into account until now. Most analyses of demand curves found in the literature aggregate all farmers, implementing a single short-run (without considering changes in irrigation systems) model for the whole set of farmers operating in the study area. Examples of such studies include those of *Wahl* [1989], *Montginoul and Rieu* [1996], *Varela-Ortega et al.* [1998], and *Gómez-Limón and Berbel* [1999]. This brings us to emphasize the importance of implementing a differential analysis and study the impact of water pricing due to the existence of a variety of responses among different groups of farmers.

[80] This paper has focused on a range of prices between 0.02 €/m^3 and 0.06 €/m^3, which we believe approximates well to likely future pricing scenarios for the implementation of the WFD. Table 4 shows the influence of these scenarios on agricultural water consumption in our case study area.

[81] The influence of the slopes (elasticities) of the water demand curves in reducing water consumption obtained through resource pricing is remarkable. It can be seen that in the more elastic (low slopes) segments of the curves the increase in the price of water produces great savings in consumption, due to changes in crop mixes and sprinkler technologies adoption, while in the more inelastic segments (higher slopes), tariff rises do not result in significant water savings, since the price rise does not persuade farmers to change their crop plans or their irrigation systems. This is the reason why the greatest savings are obtained with pricing scenarios that include more elastic segments of the water demand curves. This explains, for example, why in the case of cluster 1, the one with the most elastic demand curves (lowest slopes), the implementation of any of the scenarios for water price proposed results in the greatest water savings in relative terms.

[82] The important effects of a water pricing policy on the water saved by all clusters considered are worth mentioning. In this sense, it is interesting to note that changing present pricing system based on the irrigated surface into a volumetric water pricing would generates significant water conservation measures for all clusters, even with a subsidized price (0.02 €/m^3). For the former

Table 4. Water Consumption Reductions[a]

	Subsidized Price 0.02 €/m^3	Medium Price 0.04 €/m^3	FCR Price 0.06 €/m^3
Cluster 1,[b] m^3/ha	−1306 (−16.28%)	−3838 (−47.85%)	−7535 (−93.94%)
Cluster 2,[c] m^3/ha	−1224 (−28.74%)	−1925 (−45.21%)	−2581 (−60.61%)
Cluster 3,[d] m^3/ha	−266 (−7.11%)	−1151 (−30.74%)	−2136 (−57.06%)

[a] Reduction in water consumption as a percentage of current demand for water shown in parentheses.

[b] Current consumption is 8021.

[c] Current consumption is 4258.

[d] Current consumption is 3743.

Table 5. Reductions in Gross Margins Reductions and Public Revenues[a]

	Subsidized Price 0.02 €/m^3		Medium Price 0.04 €/m^3		FCR Price 0.06 €/m^3	
	GM Decrease	Public Revenues	GM Decrease	Public Revenues	GM Decrease	Public Revenues
Cluster 1,[b] €/ha	−206 (−32.18%)	134	−360 (−56.34%)	167	−424 (−66.28%)	29
Cluster 2,[c] €/ha	−103 (−27.08%)	61	−164 (−43.01%)	93	−198 (−52.09%)	101
Cluster 3,[d] €/ha	−91 (−15.43%)	70	−183 (−30.99%)	104	−241 (−40.73%)	96

[a] Reduction in gross margin as a percentage of current gross margins shown in parentheses.

[b] Current TGM/ha is 639.

[c] Current TGM/ha is 380.

[d] Current TGM/ha is 592.

case, these decreases in water consumption can be quantified at 16%, 29%, and 7% for cluster 1, 2 and 3 respectively. This reaction is logically more intense when ‘‘medium’’ and ‘‘FCR’’ prices are implemented. For the highest tariff considered (0.06 €/m^3), the reductions would reach 94%, 61%, and 57% of current consumption in each case.

4.4. Economic Impact

[83] The changes in gross margins motivated by the implementation of the WFD and the public revenues obtained by the different pricing levels can be seen in Table 5. Generally speaking, a water pricing policy would imply a significant fall in farmers' incomes. These losses have two causes. First, the payment of water tariffs to the State, and second, the withdrawal of crops with higher water demands (corn, sugar beet or alfalfa), that usually generate greater profits. This can be observed in Table 5, where,] for each cluster and price scenario, only part of the fall in TGM is transferred via water pricing to the State, while the remaining losses are due to changes in the crop plan and irrigation technology improvements. Such income reductions may be regarded as revenues transferred from agriculture to other sectors, since the water saved through crop changes may generate productivity increases in other activities, which would be beneficiaries of the savings in water resources (urban, industrial, environmental or recreational uses). However, it should be noted that if the water saved went to other uses that produce lower added value for society as a whole, irrigation water pricing would actually result in less efficient allocation of resources.

[84] As it is expected, the greatest income losses are produced by the highest tariff considered (0.06 €/m^3). These maximum losses in gross margins range between 41% and 66% of the current TGM, depending on the cluster. This fact might produce a large drop in agricultural competitiveness. In any case, it is necessary to emphasize that the effect on agricultural incomes would be quite important in the three clusters considered. This decrease in the profitability of irrigated agriculture might well lead in the medium and long run to the economic unsustainability of farms, which in turn might bring about the withdrawal of a large percentage of farmers from agriculture.

4.5. Social Impact

[85] Besides a reduction in water consumption, a rise in the price of water would lead to a decrease in the employment directly generated by the agricultural sector, as Table 6 shows. The decrease in agricultural employment is a social cost caused by substitution of the most water-intensive crops and furrow irrigation, which are normally also more labor-intensive, by others crops and irrigation technologies with lower water and labor requirements.

[86] These decreases in agricultural employment could be even higher than 75% of current labor demand (cluster 1 for FCR price). This could potentially have a serious social impact in the area studied. However, this drop in input demand should not be dramatized because farms in the study area are basically family operations, with only a few hired personnel. Thus this drop in demand for labor would be translated into an increase of part-time farmers, who tried to maintain their level of incomes with other nonfarm activities, or alternatively would enlarge farmers' leisure time.

4.6. Environmental Impact

[87] The introduction of irrigation water pricing would also affects nitrogen balance, as shown in Table 6. This is due to the relationship between current crop plans and the nitrogen balance. It is thus necessary to observe that certain crops such as maize or sugar beet (with high water requirements) have higher requirements for this kind of fertilization and higher nitrogen balance (much more nitrogen applied by fertilization than crop withdrawals) than others with lower irrigation needs, such as irrigated winter cereals,

Table 6. Changes in Employment and Nitrogen Balance[a]

	Subsidized Price 0.02 € /m^3		Medium Price 0.04 € /m^3		FCR Price 0.06 € /m^3	
	Employment, labor day/ha	Nitrogen, kg N/ha	Employment, labor day/ha	Nitrogen, kg N/ha	Employment, labor day/ha	Nitrogen, kg N/ha
Cluster 1[b]	−0.17 (−12.42%)	−21.77 (−15.58%)	−0.50 (−36.87%)	−66.23 (−47.40%)	−1.02 (−75.16%)	−123.54 (−88.42%)
Cluster 2[c]	−0.28 (−24.56%)	−15.82 (−25.98%)	−0.44 (−39.12%)	−22.57 (−37.05%)	−0.60 (−53.20%)	−28.11 (−46.14%)
Cluster 3[d]	−0.07 (−5.90%)	−2.32 (−3.96%)	−0.30 (−25.03%)	−14.90 (−25.44%)	−0.55 (−45.70%)	−29.28 (−49.99%)

[a] Percentage reduction in employment relative to current demand for labor and percentage reduction in nitrogen balance vis-à-vis the current situation shown in parentheses.

[b] Current TL/ha is 1.35; current kg N/ha is 139.72.

[c] Current TL/ha is 1.14; current kg N/ha is 60.91.

[d] Current TL/ha is 1.20; current kg N/ha is 58.57.

and much more than rain-fed crops. Changes in the crop plans produced by water pricing would thus decrease the consumption of nitrogen fertilizers, and thus improve nitrogen balance (less nitrogen discharges into the environment).

[88] As mentioned above, with respect to other policy makers' attributes, it is worth emphasizing how elasticity of demand will influence the achievement of the environmental objectives (e.g., a decrease in nitrogen balance) proposed. The greatest changes in the crop mixes would thus occur in the more elastic segments, where pricing policy would be most efficient.

5. Concluding Remarks

[89] The conclusions derived from the methodology employed in this paper can be summarized in terms of two fundamental points. First, it is remarkable how irrigated areas, in spite of being highly homogeneous in terms of soil, climate, market and technological conditions, show great heterogeneity in the responses of their farmers. In fact, farmers in these areas show a great variability in the management criteria that they use to plan their crop mixes. This fact makes it necessary to utilize differential modeling for the different groups of farmers in the areas under study, in order to minimize the problems of bias produced by fully aggregated models. This requires irrigators to be classified into homogeneous groups, for example, by means of a clustering technique.

[90] In second place, we wish to point out how the different types of productive behavior of the groups defined by the cluster technique can be synthesized by estimating additive MAUFs. Thus, on the basis of actual production decisions, we can estimate the different objective weightings for each cluster of farmers in order to generate their respective utility surrogate formulations. These functions are employed as objective functions in the simulation models. In this sense we consider that a methodology based on the MAUT can be a valuable technique for simulating the differentiated behavior of groups of farmers who are faced with the implementation of water pricing policies.

[91] The practical application of the methodology proposed was done in a typical irrigated area of the Duero basin, which is typical of the continental agriculture practiced in central Spain. On the basis of these results, we may conclude that the analysis of water pricing policy impacts clearly demonstrates that farmers display different behavior 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.

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