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Multicriteria analysis of derived water demand functions: a Spanish case study

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Abstract

Irrigated agriculture has been analysed in Spain in recent years because of its high water consumption and its apparent inefficiency. Several possibilities for water policy have been debated, in particular the pricing of irrigation water. This paper aims to contribute to this discussion by simulating the impact that a policy based upon the price of water could have on agricultural production, analysing the economic, social and environmental implications of such a water policy. This research introduces a methodology for deriving water-demand functions in contexts in which farmers' behaviour is not explained by the maximisation of gross margin but by a utility function with several conflicting criteria. This methodology utilises a weighted-goal programming approach to estimate a surrogate utility function for the farmer's decision process; this in turn is used to estimate the value of water demand in irrigated crop production using utility-derived demand functions. The empirical results of this study stress that water pricing as a single instrument for controlling water use is not a satisfactory tool for significantly reducing water consumption in agriculture. The reason for this is that consumption is not reduced significantly until prices reach such a level that farm income and agricultural employment are negatively affected. The results also show that the estimated water-demand curve is different when a multicriteria utility function rather than the classical profit maximisation hypothesis is employed. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

In Spain irrigated agriculture is responsible for 60% of agricultural production from 19% of the total cultivated area — 3.6 million ha — and consumes 80% of

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the total amount of water used in the country. The Mediterranean climate means that the average productivity of irrigated agriculture according to official 1997 data is 339,000 PTAs/ha as against 48,000 PTAs/ha for non-irrigated land (166.836 Spanish PTAs = 1 Euro), i.e. a 700% average increase in productivity when water is available.

Traditionally, irrigation has been the technique used to increase productivity and to enable people to settle in rural areas. Irrigated agriculture employs 550,000 rural workers, with a ratio of seven to eight times as high labour input per area as on unirrigated land, and agribusiness depends on the raw material provided by irrigated agriculture. For an introduction to irrigated agriculture in Spain see Berbel and Gómez-Limón (1999).

Spanish law defines water as a "public good"; meaning that it cannot be sold on the market. The country is divided into Watershed Management Bodies (Confederaciones Hidrograficas), which are government agencies that assign water to the management units known as "Comunidades de Regantes" (CR). These are farmers' associations that distribute water to the members of the irrigation unit.

As members of CR, farmers pay only the costs of distribution, maintenance of infrastructure, control and administration, etc., to their CR. This is computed in terms of a fixed cost per hectare, and implies a maximum amount of water available each year. Psychologically each farmer thinks that he owns the water consumed because he is 'paying for it', but this is a wrong assumption as he is actually paying only part of the distribution cost, while the water itself is absolutely free.

As a consequence of this physical and socio-economic structure and legislative framework, Spain's average consumption of irrigation water is 7225 m^3/ha, almost double the average level in Mediterranean agriculture (although 40% of farms still suffer from a shortage of water). Evidence of the scarcity of water resources in Spain was dramatically illustrated during the last severe drought (Gómez-Limón et al., 1996).

Water policy has been an important policy issue during the past few years, moving the political consensus in the direction of modernising legislation as a first step towards changing the situation. Several possibilities have been debated, especially the pricing of irrigation water.

This paper aims to contribute to this policy discussion by deriving a water-demand function that illustrates the impact that a policy based upon water pricing might have on agricultural production, and analysing the economic, social and environmental implications of such a policy. For this purpose we have utilised a methodology based upon a multicriteria model that is capable of analysing the impact through the study of relevant attributes.

2. Analytical procedure: weighted goal programming

2.1. Models of irrigated agriculture

The success of irrigation schemes depends on how producers value water and on their willingness to pay for it. The utility of irrigation water to farmers, and thus demand for it, is in terms of inputs (intermediate good) required to produce end products demanded by consumers. The willingness to pay for water depends upon the value of the output over the cost of producing that extra output (value of the marginal product of water).

A number of approaches have been made to approximating the value of irrigation water. We may quote Kulshrehtha and Tewari (1991) who show a classification of different approaches, and finally select the single-period Linear Programming Model to analyse a case study. If sufficient data can be obtained at a reasonable cost, linear programming (LP) has several advantages over other methods.

Agricultural models usually maximise profit — estimated as gross margin — as their single objective. LP has been widely used to solve companies' resource allocation problems. The model's ability to predict how companies adjust to changes under the influence of a variety of exogenous factors is well known, and particularly when used at company level, aggregation problems can be avoided.

Traditional mathematical programming based on the optimisation of a single objective may be broadened by multicriteria analysis. There are two main types of multicriteria technique: multiobjective programming, which tries to optimise simultaneously several objectives (often with many of them in conflict), and goal programming, which tries to satisfy as far as possible a set of goals compatible with the preferences exhibited by farmers.

The interest of using multicriteria decision-making (MCDM) methods in the context of the problem being analysed can be deduced from the variety of criteria that are taken into account by farmers (agricultural decision makers) when they are planning their productive activities. Thus resource allocation in farming (land, labour, water, etc.) implies the simultaneous optimisation of several conflicting criteria, and the simulation of more realistic decision-making processes will lead to a closer scenario simulation and consequently to better policy-making procedures. Evidence in favour of these affirmations can be consulted in Gasson (1973), Hatch et al. (1974), Patrick and Blake (1980), Herath (1981), Cary and Holmes (1982), Sumpsi et al. (1993, 1997), Gómez-Limón and Berbel (1995) and Amador et al. (1998).

However, in this paper we wish to look into more realistic models that combine the advantages of LP, i.e. simplicity and flexibility, with the integrative ability of MCDM models. For the reader interested in MCDM theory, we may suggest Romero and Rehman (1989) or Rehman and Romero (1993) for a review of multicriteria paradigms in agricultural economics.

2.2. Weighting goal programming for policy analysis

Both Sumpsi et al. (1993, 1997) and Amador et al. (1998) have recently developed methodologies for the analysis and simulation of agricultural systems based upon multicriteria techniques applied to irrigated agriculture. These authors propose weighted goal programming as a methodology for the analysis of decision making. This methodology has been successfully implemented on real agricultural systems (Gómez-Limón and Berbel, 1995; Berbel and Rodríguez, 1998).

We wish to employ this methodology to estimate a surrogate utility function in order to simulate farmers' decision-making processes, broadening in this way the traditional profit-maximising assumption. This surrogate utility function is then used to estimate the value of water demand in irrigated crop production, using utility-derived demand functions.

Briefly, the methodology can be summarised as follows:

1. Tentatively establish a set of objectives that may be supposed to be most important for farmers. Literature reviews, questionnaires and descriptive research are sufficient for this purpose.
2. Determine the pay-off matrix for the above objectives.
3. Using this matrix estimate a set of weights that optimally reflect farmers' preferences.

The first step in our analysis thus consists of defining a tentative set of objectives $f_1(X) \ldots f_i(X) \ldots f_n(X)$ which seeks to represent the real objectives of the farmers (e.g. profit maximisation, risk minimisation, management complexity minimisation).

Once these objectives have been defined, the second step is the calculation of the pay-off matrix, which has the following formulation:

$$\begin{array}{lcccc} & f_1(X) & f_2(X)\ldots & \ldots f_i(X)\ldots & \ldots f_q(X) \\ f_1(X) & f_1^* & f_{12} & f_{1i} & f_{1q} \\ f_2(X)\ldots & f_{21} & f_2^* & \ldots & \ldots \\ \ldots f_i(X)\ldots & f_{j1} & \ldots & f_{ij} & \ldots \\ \ldots f_q(X) & f_{q1} & \ldots & \ldots & f_q^* \end{array} \tag{1}$$

The elements of the matrix need to be calculated by optimising one objective in each row. Thus, f_{ij} is the value of the i attribute when the jth objective is optimised.

Once the pay-off matrix has been obtained, we can try to solve the following system of q (number of objectives) equations:

$$\sum_{j=1}^{q} w_j f_{ij} = f_i \quad i = 1, 2, \ldots q; \text{ and } \sum_{j=1}^{q} w_j = 1, \tag{2}$$

where f_{ij} is the pay-off matrix elements and f_i is the value achieved for the ith objective according to the observed crop distribution.

If the above system does not result in a set of w (weights of each objective that reproduce the actual behaviour of the farmer), it will be necessary to search for the best possible solution. For this purpose a weighted goal program with percentage deviational variables can be formulated (Romero, 1991). This solution will be obtained by resolving the following LP (Model (3)):

$$\text{Min}\left[(n_1 + p_1)/f_1 + \ldots + (n_i + p_i)/f_i + \ldots + \left(n_q + p_q\right)/f_q\right],$$

subject to:

$$\begin{array}{cccccccccc} w_1 f_{11}+ & \dots & +w_i f_{1i}+ & \dots & +w_q f_{1q} & +n_1 & -p_1 & = & f_1 \\ w_1 f_{i1}+ & \dots & w_i f_{ii}+ & \dots & +w_q f_{iq} & +n_i & -p_i & = & f_i \\ w_1 f_{qi} & \dots & +w_i f_{qi}+ & \dots & w_q f_{qq} & +n_q & -p_q & = & f_q \\ w_1+ & \dots & +w_i+ & \dots & +w_q+ & & & = & 1 \end{array} \tag{3}$$

where p_i is the positive deviational variable (i.e the measurement of the over-achievement of the ith objective respect to a given target), and n_i is a negative deviational variable that measures the difference between real value and model solution for the ith objective).

Our experience shows that in some cases certain objectives are closely correlated, which means that maximising one objective implies the simultaneous achievement of the rest. In such cases it may be advisable to be very selective regarding the number of objectives modelled, avoiding those that are closely related (in agricultural production, for example, sales are closely related to gross margin). The pay-off matrix (Model (1)) shows the degree of conflict among criteria, and in the hypothetical case that all objectives are closely related (maximisation of an objective implies almost optimal values for the rest); we conclude that there is no need to represent the multicriteria problem.

3. Area of study

We have applied the methodology explained above to a specific irrigation unit that is briefly described in this section. For a more detailed analysis see Berbel and Gómez-Limón (1999).

The Comunidad de Regantes "Bajo Carrión", of 6660 ha in the Mid Duero Valley, was selected in order to show the impact of the model on irrigated areas in northern Spain. Farms are usually irrigated by furrow with sprinklers used only for sugar beet. There are 907 farmers with average holdings of 7.34 ha. This irrigation unit was developed in the 1970s but became a self-organising unit in 1989.

The climate is typically continental, characterised by long cold winters followed by short, hot, dry summers. This is the most productive season, which allows a wide range of crops to be grown. This coincidence (higher temperatures and dry season) requires irrigation to allow crops to complete their growing cycle. Water demand is around 4000 m^3/ha between April and September. Farmers pay a fixed fee of 6300 PTAs per hectare (of which 4300 PTAs go to the Public Water Authority, and 2000 to the self-organised CR). A typical year without water deficit has the distribution of crops shown in Fig. 1.

We selected this region because it is relatively homogeneous and has good data availability, and because it is a modern irrigation unit that is reasonably representative of central and Northern Spain.

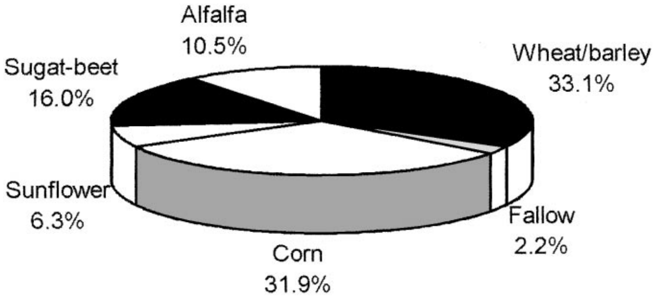

Fig. 1. Crop distribution in Bajo Carrión (Spain) irrigated area; average 1993–97.

4. Data acquisition

In this study we took particular care to gather high-quality data on the technical and economic systems of the farms concerned. Information was obtained from Government sources (regional and national), Confederaciones Hidrograficas, Comunidades de Regantes, publications and interviews with local agricultural extension services.

Secondary information was obtained by direct questioning and by analysis of farms belonging to the irrigation units. We can thus describe the system in terms of the following activities and parameters regarding crops, yields, prices, subsidies and inputs. This is the basis for eliciting the relevant attributes of the system: margins, income, variable and fixed costs, employment and other inputs.

4.1. Crops

We focus our research on the annual herbaceous crops that represent the largest proportion of irrigated production in the area of study. As herbaceous crops are the most common system of production in the area, they can be good indicators of the short-term behaviour of farmers when water policy is being changed. We also include alfalfa because of its significant share of land utilisation in the area of study.

The European "Common Agricultural Policy" (CAP) obliges farmers who are devoted to growing these crops to set aside land if they wish to receive subsidies for agricultural production. Crops available for the farmers' decision-making process vary in each area as a function of farming and physical conditions as defined by the parameters shown in Table 1.

4.2. Yields

In order to give the system as much freedom as possible regarding land use and water allocation, each activity (crop) was allocated a range of different intensities of water usage (deficit watering), giving farmers the opportunity to choose between different levels of water supply.

Table 1
Bajo Carrión (Spain) irrigation unit data

Year	Wheat	Barley	Oats	Corn	Sugar beet	Sunflowers	Alfalfa	Set-aside
Prices perceived by farmers (PTAs/kg)								
1993	24.0	22.7	21.9	26.2	7.5	31.5	15.9	0
1994	24.0	21.1	21.1	26.8	7.9	32.4	17.7	0
1995	27.1	24.1	24.6	26.8	7.8	35.2	23.6	0
1996	24.3	22.2	22.2	27.0	7.5	29.8	21.1	0
1997	23.4	21.0	21.0	23.5	7.6	32.0	21.6	0
Yield (kg/ha)								
1993	4375	4795	4828	4978	69,943	1806	11,955	0
1994	3986	4338	3985	9007	54,796	2580	9963	0
1995	3403	3653	3525	8533	61,188	2322	10,627	0
1996	4618	4715	3218	9481	66,851	2236	12,177	0
1997	4387	4479	3057	9007	63,508	2124	11,568	0
Subsidies (PTAs/ha)								
1997	26,930	26,930	26,930	58,347	26,000	48,262	0	35,249
Income (PTAs/ha)								
1993	131,799	135,909	132,847	188,615	551,275	105,208	190,331	35,249
1994	122,676	118,546	111,007	299,385	457,241	131,807	176,044	35,249
1995	119,043	114,967	113,678	287,382	502,657	130,000	250,267	35,249
1996	139,287	131,453	98,250	314,063	526,710	114,898	256,566	35,249
1997	129,589	120,987	91,137	269,661	508,661	116,240	249,406	35,249
Variable costs (PTAs/ha)								
1993	52,718	53,072	50,091	146,741	241,794	58,290	97,985	9026
1994	55,354	55,726	52,596	154,078	253,884	61,205	102,884	9477
1995	57,990	58,379	55,100	161,415	265,974	64,120	107,784	9928
1996	61,522	61,935	58,457	171,247	282,174	68,025	114,349	10,533
1997	63,525	63,952	60,360	176,823	291,362	70,240	118,072	10,876
Gross margin current (PTAs/ha)								
1993	79,081	82,837	82,756	41,874	309,481	46,918	92,346	26,223
1994	67,323	62,821	58,411	145,307	203,357	70,602	73,160	25,772
1995	61,054	56,587	58,577	125,966	236,683	65,881	142,484	25,321
1996	77,766	69,518	39,793	142,816	244,537	46,873	142,218	24,716
1997	66,064	57,035	30,777	92,838	217,299	46,000	131,334	24,373
Gross margin (1997 PTAs/ha)								
1993	95,292	99,819	99,721	50,459	372,925	56,536	111,276	31,599
1994	77,261	72,094	67,033	166,757	233,376	81,024	83,959	29,576
1995	66,881	61,989	64,169	137,991	259,276	72,170	156,084	27,738
1996	80,298	71,781	41,089	147,466	252,499	48,399	146,848	25,521
1997	66,064	57,035	30,777	92,838	217,299	46,000	131,334	24,373
Mean	77,159	72,543	60,558	119,102	267,075	60,826	125,901	27,761
Labour (Days/ha)								
	3.22	4.01	4.01	4.30	21.00	2.64	9.84	0.40
Fertiliser use (NITR/ha)								
	110	110	110	358	255	75	190	0

Yields, inputs and crop choices were determined by interviews and by questioning farmers from each irrigation unit.

4.3. Prices

Prices applied to crops are averages for the area obtained from official statistics and direct questioning (Table 1). We use historical data series for the 5-year period 1992/93–1996/97, after the prices have been adjusted for inflation (1997 PTAs).

4.4. Subsidies

Subsidies depend upon the European Union's CAP, and were therefore obtained from official publications.

4.5. Income

Income is an important attribute of the system as it defines total agricultural output. Income is computed by the simple combination of yields and prices, plus subsidies where applicable.

4.6. Variable costs

Data were collected from more than 50 farmers from the various irrigation units. We consider six categories to describe inputs and variable costs:

1. seeds;
2. fertilisers;
3. chemicals;
4. machinery;
5. labour; and
6. cost of water:
   - payment to Water Authority;
   - cost paid to the Comunidad de Regantes;
   - electricity/fuel cost of pumping; and
   - simulated price of water (to be parameterised from 0 to 60 PTAs/m^3).

Table 1 summarises the total variable costs (when the price of water is zero).

4.7. Gross margin

Data already obtained (prices, yields, subsidies and variable costs) enabled us to compute gross margins by simple calculations. Gross margin is defined as total income less total variable costs.

We use this parameter as the best estimator of short-run profit and thus as the function to be considered as an objective for the model.

4.8. Other attributes

We estimate fertiliser use (nitrogen) even if it is not a relevant attribute for farmers because it is regarded by the producers as a cost not as decision variable. Nevertheless, this criterion is relevant for policy analysis, as it may represent the environmental impact (non-point pollution caused by nitrogen fertilisation).

For policy analysis we also make a detailed analysis of water demand and labour use, as both attributes are included in the model in the objectives section (labour use) and in the constraints section (water demand). For this reason, the values of these variables will be known as outcomes of the system and will be used later in policy analysis.

5. Multicriteria model definition

We define a system via a mathematical simplification of the variables and relationships between them in order to understand the effect of any modifications of the initial conditions that characterise the system. Every system has variables that control the processes involved and that belong to the decision-making process as 'decision variables'; e.g. the farmer can decide the crop distribution or the level of use of water.

The crop plan selected will determine changes in certain attributes of the system. Attributes are relevant functions deduced from the decision variables, but as we have mentioned above, not all attributes are relevant to the decision makers. Fertiliser consumption, for example, may be an attribute of interest to policy makers but irrelevant for producers. Attributes to which decision makers assign a desired direction of improvement are considered objective functions. In this study we will analyse not only the farmers' objectives but also attributes that are relevant to policy makers, as we explain in the following section.

5.1. Variables

Each farmer who is a member of the Comunidad de Regantes has a set of variables X_i (crops), as described in the previous section and defined in Table 1. These are the decision variables that can assume any value belonging to the feasible set.

5.2. Objectives

Three objectives must be regarded as belonging to the farmer's decision-making process.

5.2.1. Profit maximisation

Farmers wish to maximise profits, but calculation of profit requires the computation of some relatively difficult factors such as depreciation. Therefore, for convenience it is assumed that gross margin (GM) is a good estimator of profit, and maximisation of profit is equivalent in the short run to maximisation of gross margin.

The objective function included in the model is defined as follows:

$$\mathrm{GM} = \sum \mathrm{GM}_i \times X_i. \tag{4}$$

5.2.2. Risk minimisation

Agricultural production is subject to price and yield fluctuations, and risk is therefore always present in any agricultural system. Many authors have proved the existence of risk-averse behaviour in farmers' decision-making processes (see Hardaker et al., 1991, 1997; Berbel, 1993; Pannel and Nordblom, 1998, for a review of recent studies and applications). Decision making therefore takes into consideration not only the classical objective of profit but also considers the risk implied by the selected crop plan.

Database developed over the period 1992/93–96/97 was used to assess total risk in terms of the variance, mathematically:

$$\text{Total risk} = \overline{x}_i^t[\mathrm{cov}]\overline{x}_i, \tag{5}$$

where [cov] is the variance/covariance matrix of gross margins from the panel data (constant 1997 PTAs) and x_i is the vector of areas of each crop in hectares.

This approach allows risk reduction by diversification among crops with negative covariance.

5.2.3. Minimisation of labour inputs

We have observed in some applications of the MCDM paradigm to agricultural systems that farmers display a certain aversion to hiring labour (Amador et al., 1998). One explanation for this behaviour has been that the parameter is related to crop complexity, and that hired labour adds a degree of complexity to family farming.

For this reason, labour is computed as the sum of labour for all farming activities (TL), and its objective function will be as follows:

$$\sum \mathrm{TL}_i \times X_i = \mathrm{TL}. \tag{6}$$

We introduce the objective of minimising labour because 'a priori' (i.e. interviews with farmers and experts) it is a relevant criterion.

Furthermore some other applications of this method in the literature have proposed additional criteria such as minimising working capital, minimising the gross margin/working capital ratio, minimising 'crop difficulty', etc. (Sumpsi et al., 1993, 1997; Amador et al., 1998). Our experience shows that analysts may introduce any number of criteria that may be relevant according to the previous field research for each system.

As we mention in the definition of attributes, fertiliser minimisation is not taken into account in the model because it is only a public objective. For this reason it is not considered in the decision process by farmers (Zekri and Romero, 1993). As a result, no other objectives are proposed in advance. We will assume that the three objectives mentioned above are enough to explain farmers' behaviour.

5.3. Constraints

5.3.1. Total cultivation area

All crops (X_i) must add up to 100. This constraint is only introduced in order to obtain the outcome of the model (decision variables X_i) as percentages.

5.3.2. CAP

A large proportion of agricultural income depends upon CAP subsidies, and farmers cannot afford to ignore CAP regulations that affect most of the crops available for cultivation. For this reason, in accordance with CAP rules, we need to include set-aside activity (SA) related to the subsidised crops (which are the majority):

$$\sum X_i + \mathrm{SA} = 100. \tag{7}$$

This SA, as a CAP requirement, must be at least the 5% of the land that is occupied by cereals and sunflowers.

Sugar beet is also constrained to be less than the historical quota assigned to each farmer. At the regional level, this historical quota (period 1991/92–96/97) is obviously an upper limit.

5.3.3. Market and other constraints

Some of the crops are not subject to CAP rules but marketing channels put an upper limit on short-term variations. This is the case for alfalfa. This crop needs to be produced in quantities that processing facilities, the marketing system or livestock in the vicinity of the production area will demand without price distortions. For this circumstance a 'greater-than' constraint has been included in the model. We have fixed this upper limit on the basis of the maximum historical cultivation during the period 1991/92–96/97.

5.3.4. Rotational and agronomic considerations

Agronomically it is regarded as sound policy not to cultivate a crop such as a cereal if, during the previous year, the same plot has grown another cereal. This is called a rotational constraint. This limits the cultivated area for a crop to a maximum of 50% of the total available area, and applies to all crops except alfalfa.

As alfalfa remains in cultivation for 4 years, and it is recommended to rest the plot for 3 years thereafter, we set up a constraint to respect this agronomic consideration:

$$X_{18} = \text{Alfalfa} \leqslant \frac{m}{m+n} S = \frac{4}{4+3} 100 = 57.14. \tag{8}$$

All this information has been included in the model that forms the basis for the MCDM simulation.

We also include some attributes that are to be analysed later in the study, but that are not taken into consideration in the farmers' decision-making process.

5.4. Attributes

Attributes are values of interest for the analyst that are deduced as functions of decision variables. In this sense we have considered several attributes that are relevant to policy makers. The model used in this study has been developed in order to estimate the values of these attributes (not relevant to the decision maker) at the same time as the decision variables. The analysed attributes are:

1. Water consumption: the projected consumption of water, measured in m^3/ha, is the variable that policy makers wish to control as a consequence of changes in water management policy.
2. Economic impact: we measure the economic impact of changes in policy by measuring two variables: agricultural income and public-sector revenue from water pricing, both measured in PTAs/ha.
3. Social impact: since irrigated agriculture is the main source of employment in many rural areas of Spain, any change in policy will significantly affect the social structure of rural areas. This attribute is measured in labour-days per hectare (Day/ha).
4. Environmental impact: the main environmental impact of irrigated agriculture is water consumption itself, with the creation of a mosaic landscape and a rise in crop diversity and humid areas. In addition to this positive impact, however, comes an increase in the use of fertilisers and chemicals that are the main source of non-point source pollution in agriculture. We use the demand for fertilisers as an indicator of the environmental impact of irrigated agriculture, measured in kilograms of nitrogen added per hectare (N/ha).

6. Weighted goal programming process

The weighted goal programming (WGP) proposed by Sumpsi et al. (1993, 1997) aims to find weights that will bring the decision-making plan as close as possible to the farmer's real-life decision plan. Applying the above-mentioned algorithm to our model, we solve it as follows:

Step 1: Formulate the three hypothesised objectives $f_i(x)$, $i=1,3$.
We select the three objectives described above with their respective mathematical functions (max. gross margin, min. variance and min. labour).

Step 2: Obtain the pay-off matrix by solving the program (single objective max./min.).

$$\text{Optimise } f_1(x), \text{ subject to } x \, \varepsilon \, F. \tag{9}$$

The optimum of Eq. (9) $f_1{}^* = f_{11}$ is the first entry in the matrix. To obtain the other terms in the first column we need only to substitute the optimum vector of decision variables provided by the same Eq. (9) in the remaining $i=2$ and $i=3$ objectives.

The main diagonal will contain the three independent optima for the three objectives. Meanwhile, the values for the rest of the criteria can be seen in each column. Table 2 shows the pay-off matrix.

We can see a certain degree of compatibility between the second and third objectives, and how both conflict strongly with gross margin.

On the other hand, the last column shows real (observed) data for the whole region analysed (irrigated system). These values show actual crop distribution (considering a theoretical 100 ha farm) and the relation among different crops and the objectives considered [GM, variance (VAR) and TL]. We can see how far the real situation (1998) is from any single optimum (column). This may induce us to try a combination of objectives as a better simulation of farmers' behaviour. This is the basis for the multicriteria theory and for the methodology described in this paper.

Step 3: Obtain the set of weights that best reflects farmers' preferences.
When we solve Model (3) by using data with real values for objectives and in the equations, the solution is:

$$W_1(\text{maximise GM}) = 0.8321$$
$$W_2(\text{minimise risk VAR}) = -0.1679$$
$$W_3(\text{minimise labour TL}) = 0.0000$$

The set of weights is compatible with a type of behaviour that combines profit maximisation (weighted by 83.21%) and risk avoidance (16.79% weight). It is important to note that although we proposed labour minimisation (management complexity) as an objective taken into account by farmers, the results have shown us that this hypothesis was wrong and actually total labour is not considered as a relevant criterion in this particular agricultural system.

The estimation of these weights is based on the current situation, i.e. the price of water is zero. In this sense it is important to note that we assume that this set of weights can be considered as a structural factor. As these weights correspond to the producers' psychological attitudes, it is reasonable to assume that they will be

Table 2
Pay-off matrix (100 ha)

Values	Optimum			Real
	GM	VAR	TL	
Gross margin (GM)	14,127,856	3,413,705	2,776,138	12,328,862
Variance (VAR)	39,454	558	863	21,283
Total labour (TL)	810.3	93.9	40.0	706.5

kept at the same level at short and medium run, and this is in fact the key assumption in our simulation. In the next section, in order to simulate water-price scenarios, we will use these weightings to represent the farmers' utility function, which will be as follows:

$$U = 83.21\%\ \mathrm{GM} - 16.79\%\ \mathrm{VAR}. \tag{10}$$

However, if we intend to include this utility function in our decision model we ought to use 'normalised weightings' because only by using non-dimensional weightings can algebraic operations be implemented. Sumpsi et al. (1997) suggest dividing the value of the objective by the range between the best and worst values of each one in the pay-off matrix (known in multicriteria terminology as "ideal" and "anti-ideal"). For example, gross margin is divided by (14,127,856–2,776,139) and variance is divided by (39,454–558) resulting in the following transformed utility function:

$$U = 7.33 \times 10^{-8}\ \mathrm{GM} - 431.69 \times 10^{-8}\ \mathrm{VAR}. \tag{11}$$

Dividing all the utility functions by 10^{-8}, the operative expression of U can be expressed as follows:

$$U = 7.33\ \mathrm{GM} - 431.69\ \mathrm{VAR}. \tag{12}$$

This expression that the model will attempt to maximise will be employed in the subsequent simulation.

It is essential to compare the real (observed) situation with the situation predicted with the help of the estimated utility function (Eq. (12)). Table 3 shows that this methodology produces a better approximation to observed values at the present water price level (zero).

Finally, we wish to mention that an alternative model using the MOTAD method (Hazell, 1971) instead of variance as a risk estimator placed a weight in the risk criteria equal to −24.23%, but this MCDM model was rejected because it was a poorer approximation to observed values than the MCDM model using variance as risk estimator.

7. Multicriteria utility water demand

The surrogate utility function (Eq. (12)) is used to estimate the value of water demand in irrigated crop production using the model described with the following adaptations:

1. function to be optimised is above function (12);
2. gross margin includes the extra cost of water; and
3. we introduce crops that require various levels of irrigation in order to allow the system to adapt to the rising cost of irrigation.

Table 3
Model validation (100 ha)

	Observed values	Profit max. model		MCDM model	
		Mod. values	% deviation	Mod. values	% deviation
Objective space					
Gross margin	12,328,862	14,127,856	12.73	13,567,341	9.13
Variance	21,283	39,454	−46.06	25,362	−16.08
Total labour	706.5	810.3	12.81	795.8	11.22
Decision space					
Winter cereals	33.10	14.37	18.73	29.94	3.16
Corn	31.94	50.00	−18.06	34.44	−2.50
Sugar beet	15.97	20.50	−4.53	20.50	−4.53
Sunflower	6.25	0.00	6.25	0.00	6.25
Alfalfa	10.53	11.91	−1.38	11.91	−1.38
Set-aside	2.20	3.22	−1.02	3.22	−1.02
Total	100.00	100.00	49.97	100.00	18.84

Yields, inputs and choices of crop were obtained by means of interviews and questioning of farmers belonging to each irrigation unit. The results of this procedure are shown in Table 4, where we can see that a crop (e.g. sugar beet) is represented by three different decision variables or activities). The crop variable is followed by a number which represents the amount (thousands) of cubic metres of water employed per hectare. Of course, for each water supply, the crops will have different productivities, e.g. "Sugar Beet 4.2" (X_{12}) means crop irrigated with 4200 m^3 producing 65,000 kg/ha, "Sugar Beet 3" (X_{13}) means irrigation with 3000 m^3 yielding 55,000 kg/ha, etc. Data were obtained by questioning farmers directly (see data acquisition).

We also include non-irrigated crops such as Wheat 0, which indicates standard rainfed conditions. Climatic conditions in Spain allow wheat, barley, oats and sunflowers to grow under rain-only water supply. Finally, set-aside is considered as another activity linked to crop planning. As a result, decision variables consist of 20 crops; each combined with a water supply level.

Each of these modified irrigated crops includes coefficients for labour, fertiliser and other inputs.

8. Results

This section studies the impact of rising water prices on the relevant attributes of the system in order to contribute to the political discussion. Table 5 shows crop distribution as a response to changes in the price of water.

Table 4
Crop variables with deficit irrigation

Crop	Variable	Yield (kg/ha)	Total labour (Days/ha)	Fertilisers (N/ha)
Wheat 2.8	X_1	4300	3.2	110
Wheat 1.4	X_2	2500	2.8	99
Wheat 0	X_3	2000	2.4	89
Barley 2.8	X_4	4000	4.0	110
Barley 1.4	X_5	3000	3.6	99
Barley 0	X_6	2500	3.2	89
Oats 2.8	X_7	4000	4.0	110
Oats 1.4	X_8	3000	3.6	99
Oats 0	X_9	2000	3.2	89
Corn 7.2	X_{10}	8000	4.3	358
Corn 5.7	X_{11}	7000	3.9	322
Sugar beet 4.2	X_{12}	65,000	21.0	255
Sugar beet 3.6	X_{13}	55,000	21.0	230
Sugar beet 3	X_{14}	30,000	21.0	207
Sunflowers 2.8	X_{15}	2300	2.6	75
Sunflowers 1.4	X_{16}	1800	2.2	68
Sunflowers 0	X_{17}	1000	1.8	61
Alfalfa 7.2	X_{18}	12,000	9.8	190
Alfalfa 5.7	X_{19}	10,000	9.4	171
Set-aside	SA	0	0.4	0

We will focus on two issues:

1. from the policy viewpoint, the different impacts of water pricing; and
2. from the methodological viewpoint, the differences between the classical LP model and the multicriteria (weighted goal) model.

A detailed classical gross margin maximisation LP model for three irrigation units in Spain (including this area) can be seen in Berbel and Gómez-Limón (1999).

8.1. Water consumption

When we solve the system by optimising the utility function (Eq. (12)), the demand for water from the present level (zero) to 60 PTAs/m^3 is shown in Fig. 2.

Fig. 2 shows a typical demand curve that reflects how the farmer adapts to the rising cost of a production factor. We can also see the 'classic' demand curves derived from the profit-maximising approach.

It is interesting to observe the similarities and differences between the two curves. We can see that 'multicriteria demand' starts from 4750 m^3, as against 5000 m^3 for the profit-maximising demand, indicating different crop plans. Evolution is also 'smoother' and irrigated cultivation is maintained until the price of water reaches 59 PTAs/m^3, while the demand for water reaches zero at 62 PTAs/m^3 for the profit-maximising function.

Table 5
Simulated crop areas with MCDM hypothesis (100 ha)[a]

Price	WHE 2.8	BAR 0	CORN 7.2	CORN 5.7	S.B. 4.2	S.B. 3.6	SUN 0	ALF 7.2	S.A.
0	29.94		13.00	21.44	20.50			11.91	3.22
1	31.03		11.59	21.75	20.50			11.91	3.22
2	32.11		10.18	22.07	20.50			11.91	3.22
3	33.20		8.78	22.39	20.50			11.91	3.22
4	34.29		7.37	22.71	20.50			11.91	3.22
5	35.38		5.96	23.03	20.50			11.91	3.22
6	36.47		4.56	23.35	20.50			11.91	3.22
7	37.56		3.15	23.67	20.50			11.91	3.22
8	38.65		1.74	23.98	20.50			11.91	3.22
9	0.04	39.43		24.90	20.50			11.91	3.22
10	0.40	41.36		24.33	20.50			10.10	3.30
11	0.04	47.33		22.59	20.50			6.04	3.50
12		50.00		22.04	20.50			3.86	3.60
13		50.00		22.33	20.50		0.40	3.13	3.64
14		50.00		20.35	20.50		5.36		3.79
15		50.00		17.82	20.50		7.89		3.79
16		50.00		15.29	20.50		10.42		3.79
17		50.00		12.76	20.50		12.95		3.79
18		50.00		10.23	20.50		15.48		3.79
19		50.00		7.71	20.50		18.01		3.79
20		50.00		5.18	20.50		20.54		3.79
21		50.00		2.65	20.50		23.06		3.79
22		50.00		0.12	20.50		25.59		3.79
23		50.00		0.12	20.50		25.59		3.79
24		50.00		0.12	20.50		25.59		3.79
25		50.00			20.50		25.71		3.79
26		50.00			20.50		25.71		3.79
27		50.00			20.50		25.71		3.79
28		50.00			20.50		25.71		3.79
29		50.00			20.50		25.71		3.79
30		50.00			20.50		25.71		3.79
35		50.00			20.50		25.71		3.79
36		50.00			19.26	1.24	25.71		3.79
37		50.00			18.10	2.40	25.71		3.79
38		50.00			18.10	2.40	25.71		3.79
39		50.00			19.26	1.24	25.71		3.79
40		50.00			16.94	3.56	25.71		3.79
45		50.00			13.93	5.30	26.92		3.85
50		50.00			10.32	2.27	29.14		8.27
55		50.00			4.67		31.78		13.55
60		50.00					33.33		16.67

[a] Activities: Wheat 1.4, Wheat 0, Barley 2.8, Barley 1.4, Oats 2.8, Oats 1.4 Oats 0, Sugar beet 3, Sunflowers 2.8, Sunflowers 1.4 and Alfalfa 5.7 are not mentioned in the table because they are not considered at any water price.

The smoother curve of the multicriteria demand function in comparison with classical profit maximisation is explained by crop plans that are formed by the smaller number of crops grown when profit is the only objective, and only the most

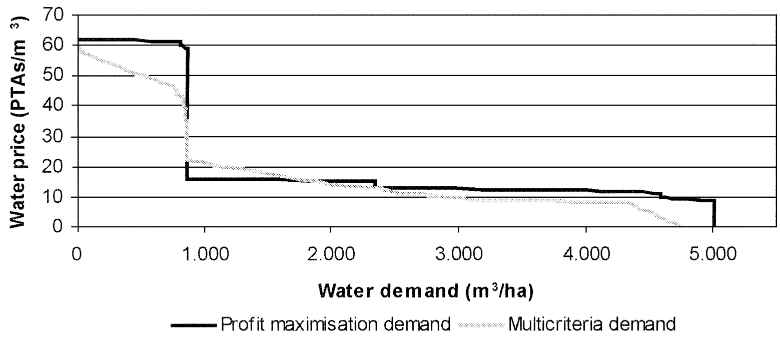

Fig. 2. Irrigation water demand; MCDM versus profit maximisation.

profitable crops are included. On the other hand, when risk minimisation is taken into account, such as in the utility function (Eq. (12)), the farmer tries to diversify his activities by bringing a wider variety of crops into the cultivation plan.

We believe that this behaviour is more realistic and we will use the multicriteria function to analyse the impact of water pricing, as an illustration of the potential use of this methodology. As the price of water rises, farmers adapt by changing their crop plans in order to obtain the best results from the use of this resource. In our case, the best result is defined as the optimum of the multicriteria objective function (Eq. (12)).

The different slopes of the demand curve are due to changes in the crop plan, as an adaptation to the rising cost of water resources: low water prices imply high-consumption crops (corn, sugar beet, alfalfa), but as the price of water increases, corn is replaced by winter cereals (wheat, etc.) and sunflowers. A very high price implies water being used almost exclusively for sugar beet with the rest of the land growing non-irrigated field crops (dry cereals and sunflowers).

A detailed analysis of the water demand with consequences for policy analysis can be seen in Berbel and Gómez-Limón (1999).

8.2. Economic impact

Pricing of water results in a serious reduction in farm income as is shown in Table 6 and Fig. 3 (remember that in Spain the price of water is currently zero).

This reduction is a consequence of two factors that operate in the same direction:

1. Public-sector revenue payment for water means a transfer of income from the farming sector to the public sector, with the aim of redistributing it for environmental improvements or integrated rural development. However, in the first instance it is a burden to be borne by the farmer.
2. Farmers respond to price increases by reducing their water consumption through changes in crop plans, introducing less profitable crops as substitutes for the more valuable water-intensive crops. This change significantly decreases farmers' incomes (sales income declines much more than costs).

Table 6
Development of income, public-sector revenue, labour and fertiliser under MCDM hypothesis

Price	Water consumption reduction (%)	Gross margin reduction (GM)		Public revenue (PTAs/ha)	Labour reduction (%)	Fertiliser reduction (%)
		PTAs/ha	% initial GM			
0	0	0	0	0	0	0
1	1	5227	4	4700	0	1
2	2	10,351	7	9296	0	3
3	3	15,371	10	13,789	0	4
4	4	20,289	14	18,179	1	5
5	5	25,103	17	22,466	1	6
6	7	29,813	20	26,650	1	8
7	8	34,421	23	30,730	1	9
8	9	38,926	26	34,707	1	10
9	34	43,610	30	28,385	2	15
10	37	47,062	32	30,011	3	16
12	49	52,918	36	28,900	9	22
14	57	57,725	39	28,465	13	26
16	63	61,510	42	27,870	14	32
18	69	64,130	43	26,110	16	38
20	76	65,585	44	23,186	17	44
25	82	68,409	46	21,525	18	50
30	82	72,714	49	25,830	18	50
35	82	77,019	52	30,135	18	50
40	82	81,941	55	33,586	18	50
45	84	87,160	59	34,914	22	51
50	89	93,839	63	25,766	39	58
55	96	98,315	67	10,787	59	66
60	100	99,546	67	0	71	71

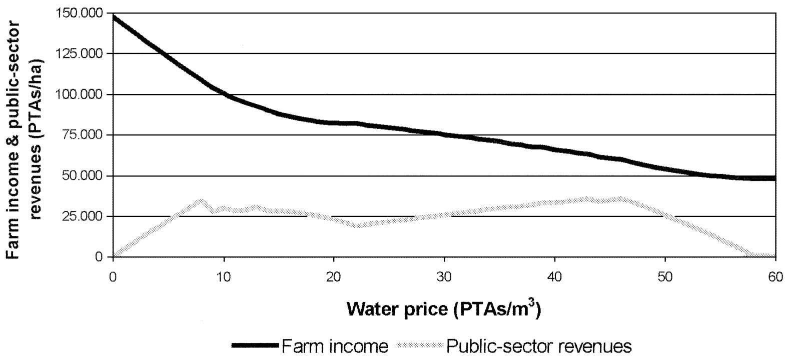

Fig. 3. Farm income and public-sector revenues (MCDM hypothesis).

Income reduction is most severe when the price reaches 8 PTAs, with a fall in income of around 26%, while water consumption is reduced only 9%. The losses of income in the private sector are mainly transferred to the public sector — not to water saving — because crop plans are not modified significantly, and demand for water is basically maintained.

The existence of a first, rather inelastic, segment that does not respond significantly to price rises is relevant for policy making. If water pricing is the only instrument for reducing water consumption in the short run, this inelastic segment implies that significant water savings are to take place, it will be necessary to raise prices beyond 8 PTAs/m^3, and this threshold price would imply that farms incomes will suffer large losses of income.

On the other hand, once the threshold of 8 PTAs/m^3 is passed the crop plan reflects substitutions and variations as response to price rises. This implies that the transfer of income from farming to the public sector is not as direct as below the threshold (8 PTAs/m^3) because farm income losses above the threshold of 8 PTAs/m^3 are due primarily to crop substitutions and only secondarily to payments to the public sector

Fig. 3 shows that public-sector revenue reaches a maximum at a price of 8 PTAs/m^3. Once this level of water price has been passed, the impact of falling demand for water (because crop substitutions) out-weighs the impact on public-sector revenue of price of water. This up-down evolution is similar to the behaviour of a monopoly firm (the Government owns the monopoly of water)

8.3. Social impact

Pricing of water brings about a severe reduction in farm labour inputs in the short run as a result of responses to price increases by reducing water consumption through changes in crop plans, introducing less profitable crops as substitutes for higher-value/higher labour- or water-intensive crops. This implies that water-intensive crops such as corn and sugar beet will be replaced by less demanding and more mechanised crops such as cereals and sunflowers. This circumstance, in relation to labour, can be observed in Fig. 4 where we can see how farmers' behaviour varies when demand is based on multiattribute utility against profit maximising model.

Table 6 summarises these observations, showing how a water price below the 8 PTAs/m^3 threshold is characterised by a relatively stable crop plan without

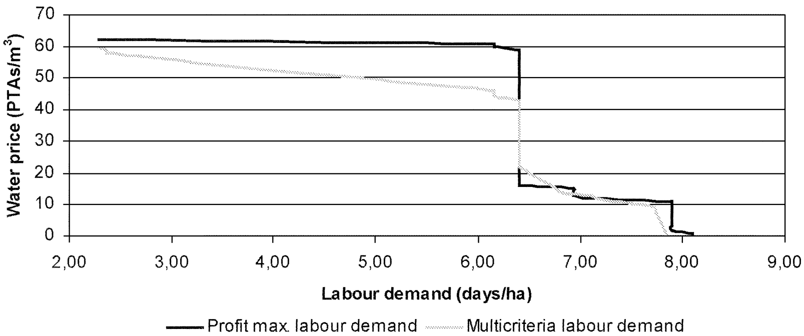

Fig. 4. Labour demand MCDM versus profit maximisation.

significant impact in labour demand. On the other hand, above this price threshold, the crop plan varies dramatically, bringing about a large fall in the demand for labour.

We should stress that rural Spain depends on agriculture as its principal source of employment, and that a reduction as simulated by a price above 8 PTAs/m^3 will seriously affect rural employment. Our estimate is that rural employment in the area would fall to 70% of the levels reached under full irrigation regimes.

8.4. Environmental impact

Fig. 5 and Table 6 in the previous section showed that water pricing leads to a significant reduction in fertiliser use as a result of modifications of crop plans and the introduction of less productive crops. Agricultural production in Mediterranean climates is directly related to the availability of water as the most important limiting factor.

Obviously, as farmers substitute crops in order to save water, fertiliser use directly decreases, and we should remember that using fertilisers beyond soil capacity when water is not available has a negative impact on both soil structure (salinitation) and crop yields (Domínguez, 1997).

Reduction in the use of fertiliser use is significant over the price threshold 8 PTAs/m^3, with reductions in comparison with initial levels of around 28 and 67%, respectively. This will obviously have a positive impact in the reduction of non-point chemical pollution by agriculture.

However, efficient fertilisation is more dependent on the use of sound fertilising techniques than on the total amount of fertiliser used. Serious efforts should be put into minimising the impact of fertilisers through rural extension services and agricultural research (Zekri and Romero, 1993).

We believe that saving water is an objective itself, because water not used may be devoted to expanding wetlands or simply to increase flow in the rivers with benefit to the environment, quite apart from considerations of fertiliser use. But the findings of this paper are that the price of water would have to be increased to as much as

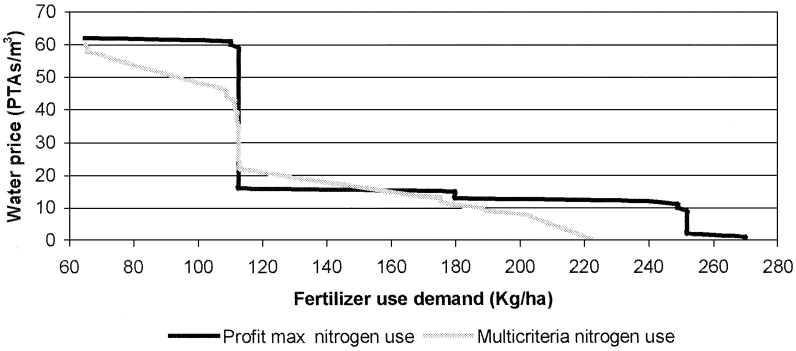

Fig. 5. Fertiliser use MCDM versus profit maximisation.

8 PTAs if it is to have a significant impact on water consumption (10% reduction), with a 26% reduction in farm income, which we regard as a high price to be paid for water conservation. Therefore we would recommend that priorities be put upon volume control (and reducing distribution losses) that will lead to similar saving without the social cost of a policy of pricing.

9. Concluding remarks

From the point of view of agricultural policy we find that the number of available crops in the area studied is very small, and note that almost all crops cultivated by farmers under irrigation are under CAP control. We can also see how sugar beet and corn are the basis for the economic viability of irrigated agriculture in northern Spain, and consequently for rural development and subsistence. We suggest that public- and private-sector efforts should be put into reducing the heavy dependence of irrigated agriculture (and hence the economy of rural areas) on a very small number of crops.

If water pricing is selected as a policy tool, we predict that some of the consequences for the agricultural sector will be:

1. Economic: farm incomes will fall by around 25% before water demand starts to decrease significantly (10%). The impact of this reduction on the rural areas that depend upon irrigated agriculture will be catastrophic.
2. Social: when water consumption decreases as a result of the substitution of crops with high demands (sugar beet, corn) there will be a significant loss of employment, both directly on farms and indirectly on processing facilities
3. Environmental: there will be a reduction in fertiliser use, but the environmental impact of fertiliser use could also be reduced significantly by improved agricultural practices. It is difficult to determine the environmental benefits of pricing water.

These conclusions are drawn from the analysis of a representative irrigated farming community in Spain, but we believe that they are capable of making a contribution to the policy debate on normative innovations on the irrigated sector of Spanish agriculture.

From the empirical point of view we wish to remark that our results show how farmers' behaviour is better simulated by a utility function involving several criteria, which differs somewhat from the traditional profit-maximisation assumption. This is of special interest when results are to be considered for policy making, as is the case with water in Spain at the present.

From a methodological point of view, we confirm our interest in continuing research into modelling irrigated agriculture, especially when a policy change is under discussion. It would be interesting to complement short-term analysis of response with long-term dynamic adaptation models, including analyses of technical change (adoption of water-saving techniques). Furthermore, in order to build more realistic models, multicriteria techniques such as those employed in this study should be adopted for further analyses of irrigated agriculture.

Finally, we would like to see the analytical tools outlined in this paper treated as a valid methodology for dealing with farmers' utility functions and thus for producing more realistic policy-impact simulations.

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