Local water markets for irrigation in southern Spain: A multicriteria approach[†]

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Spanish authorities have recently approved a new legislative framework for the creation of local water markets to improve allocative efficiency for this scarce resource. This paper analyses the potential impacts of the policy. A utility function for three groups of farmers was elicited, using a method that does not require interaction with the decision-makers. Utility was measured as a function of the first two moments of the distribution of total gross margin. The utility functions were then used to simulate farmers' responses to changes in the price of water.

1. Introduction

In Spain, irrigated agriculture accounts for 60 per cent of agricultural production. Only 19 per cent of that area is cultivated (3.6 million hectares) and consumes 80 per cent of the total water supply. Due largely to the Mediterranean climate, the average productivity of irrigated agriculture is 339 000 Ptas/ha[1] compared to 48 000 Ptas/ha of non-irrigated land (Ministerio de Medio Ambiente 1998).

Spanish law defines water as a 'public good' that cannot be privately traded. Spanish territory is divided into Regional Water Authorities or watershed management bodies, called *Confederaciones Hidrograficas*. These are governmental agencies that assign water to the irrigation management units known as *Comunidades de Regantes*. These farmers' associations distribute water to the members who pay the costs of distribution,

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[1]166.386 Ptas = 1 Euro; 185 Ptas = US $1, at 23/02/01.

maintenance of infrastructure, control and administration, etc., to the management unit. These costs are computed per hectare and a given maximum amount of water is made available each year.

Psychologically each farmer assumes that they have paid the full cost of the water. In fact, only part of the distribution cost is paid as a fixed water charge by the farmer. The marginal cost per cubic metre of water is zero.

Because of this allocative framework, a large amount of water is used to irrigate crops subsidised under the Common Agricultural Policy (CAP). These crops are grown under extensive conditions that have low productivity and low labour demand. In addition, the amount of water loss in the distribution channels and the heavy consumption of water at the plot level has moved the political consensus in the direction of modernising legislation as a first step towards changing the situation. These are the main reasons behind the recently approved measure for changing the current system. The new legislation will enable farmers to sell their concessions to other farmers, thus facilitating the development of a local water market.

The aim of this paper was to forecast the behaviour of farmers facing a local water market. A methodological framework was developed to assess the consequences of the introduction of water markets for farm incomes and levels of employment. For this purpose, we used a multicriteria model to simulate the farmers' decision-making process in a community of southern Spain (El Bajo Guadalquivir).

2. Methodology

In modelling farmers' behaviour, two approaches were commonly used: (i) mathematical programming; and (ii) econometric models. Kingwell (1996) outlines some advantages of mathematical programming over econometric models. First, it does not require long data series and second, it readily incorporates interactions between alternative activities and the effect of constraint limitations simultaneously. These circumstances led us to choose this analytical framework in order to achieve the objective proposed earlier.

On the other hand, mathematical programming has significant disadvantages, such as needing to define the list of activities and technology alternatives to be included and the danger of aggregation bias. To limit the effect of aggregation bias we grouped farmers into subsets with similar crop distributions and constraint levels. To avoid overspecialisation of the model farm plans, prices for vegetables were treated as being endogenously determined, declining as production was increased.

There are a number of studies based on modelling water markets (e.g. Garrido, 1995; Sumpsi *et al.* 1998). From an empirical point of view the studies of Weinberg *et al.* (1993), Booker and Young (1994) for California, Becker (1995) for Israel and Garrido (1998) deserve attention. In general, these authors conclude that the implementation of a local water market increases the efficiency of allocation of this resource.

Although our work was influenced by the aforementioned studies, the methodological approach we used was somewhat different. We assumed that, unlike in the classical approach, the farmer's utility level was determined not only by profit but also by a measure of risk (the variance as the second statistical moment of the profit). Thus, the amount of water that farmers demand depends on the value of the utility function and not exclusively on the productivity of this resource.

Although an economic agent deals with many criteria in the decision-making process, economic theory has conventionally used models with a single, well-defined objective that is optimised (e.g. profit). Hurwicz (1973) considers that this simplification of reality was a necessary step in the progress towards a solution to multicriteria problems. Friedman (1962) criticises the single-objective approach, arguing that this approach treats choice simply as a technological problem without value judgements in its solution. Von Neumann and Morgenstern (1944), in one of the first works on multicriteria analysis, explain economic acts as a result of many, usually conflicting, objectives. In the agricultural field there are many researchers who favour the use of multicriteria decision-making techniques (MCDM) (e.g. Hazell (1971); Gasson (1973); Hatch *et al.* (1974); Herath (1981); Rehman and Romero (1993); and Amador *et al.* (1998)).

For the purposes of this study it was assumed that the farmer's objective was to maximise a weighted sum of the expected income (total gross margin) and its variance. This approach may be justified either as a case of an additive form of Multi-attribute Utility Theory (MAUT) or as the expected value of a quadratic utility function.

2.1 MAUT and the form of the utility function

It is often argued that MAUT has the most sound theoretical structure of all the multicriteria techniques (Ballestero and Romero 1998). At the same time, from a practical point of view, the direct elicitation of utility functions presents many drawbacks. In this paper, we used a methodology that overcame these limitations.

In MAUT, the utilities of n attributes of alternative options are captured in a quantitative way via a utility function. Mathematically, $U = U(x_1, x_2, ..., x_n)$.

If these attributes are mutually utility-independent[2] the formulation becomes $U = f\{u_1(x_1), u_2(x_2), \ldots, u_n(x_n)\}$ or in simple additive form:

$$U(x_1, x_2, \ldots, x_n) = \Sigma w_i u_i(x_i), \; i = 1, 2, \ldots, n \tag{1}$$

where it is often assumed that $0 \le w_i \le 1$ and $\Sigma\, w_i = 1$ (Keeney 1974).

The additive utility function has been widely used to model farmers' decisions when the uncertainty attribute is involved. The ranking of alternatives is obtained by adding contributions from each attribute. Because attributes are measured in different units, normalisation is required to allow addition. Each attribute's weight expresses its relative importance.

Fishburn (1982) presents the mathematical requirements for assuming an additive function. From a practical point of view, two conditions must be satisfied (Hardaker *et al.* 1997). First, attributes must be preferentially independent. The level of one attribute must not affect the preference for any other attribute. Second, the utility value of one attribute must be independent of the level of another.

Although these conditions are restrictive, Edwards (1977) and Farmer (1987) have shown that the additive function yields extremely close approximations to the hypothetical true function even when these conditions are not satisfied. In Hwang and Yoon's words (1981, p. 103): 'theory, simulation computations and experience all suggest that the additive method yields extremely close approximations to much more complicated non-linear forms, while remaining far easier to use and understand'. Hardaker *et al.* (1997, p. 164) consider this approximation as reasonable over a relatively narrow range of values.

Once the use of the additive utility function had been justified, we took a step further and assumed that the individual attribute utility functions were linear. Hence, expression 1 takes its simplest form, mathematically:

$$U_i = \sum_{j=1}^{n} w_j r_{ij}, \quad i = 1, \ldots, m \tag{2}$$

where U_i is the utility value of alternative i, w_j is the weight of attribute j and r_{ij} is the value of attribute j for alternative i.

Although the assumption of linearity of the individual attribute utility function is rather strong and may be unrealistic, the validation of the model supports this decision. Because our aim was to rank alternatives in the same way the decision-maker would do, the precise mathematical form of the utility function was of secondary importance. The findings of this study

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[2]An attribute x_i is utility-independent of the other $n - 1$ attributes x_j if preferences for lotteries involving different levels of attribute x_i do not depend on the levels of the other $n - 1$ attributes x_j. See for example Huirne and Hardaker (1998).

suggested that the estimated utility functions were a good approximation to the farmers' own utility functions. Furthermore, the use of the expected value variance (E-V) linear approximation gave a local measure of risk aversion.

2.2 Attributes of the utility function

For the elicitation of the utility functions two attributes were used:

1. Expected total gross margin, as a measure of the achievement of the objective of profit maximisation. There were two implicit assumptions: (i) that utility or preferences can be evaluated just as well in terms of total gross margin (TGM) and net income; and (ii) that fixed costs were not stochastic.
2. Variance of the TGM, as a measure of the achievement of the objective of risk minimisation. Because the aim was to minimise the variance, the values r_{ij} are defined as the negative of the variance.

The choice of attributes was supported by a survey of 65 farmers in the area studied. One question in the survey was intended to rank the farmers' objectives from one to four. Three objectives were suggested by the authors: (i) maximisation of gross margin; (ii) minimisation of risk; and (iii) minimisation of labour hire. Hardly anyone mentioned a fourth objective. Thus, 22 farmers claimed that the maximisation of total gross margin was their only objective. When considering two objectives, the most common answer was, first, the maximisation of gross margin, and then, the minimisation of risk (26 farmers). Only one-third of all farmers mentioned three objectives, and among them, 73 per cent ranked the maximisation of gross margin and the minimisation of total risk as the two most important objectives. Based on these results, it was concluded that the maximisation of total gross margin and the minimisation of risk provided a good approximation to the true utility function. The observed differences among survey farms in their choice of crops was attributed to differences between farmers' utility functions.

A second issue was the choice of the variance as a measure of risk, and not, for example, the standard deviation or the total absolute deviation (TAD). In order to test the effect of different measures of risk on the ranking of alternatives, we built one utility function with the attributes expected total gross margin and variance, and two others with the same measure of expected value but using the standard deviation or the TAD as a measure of risk (the elicitation procedure is explained below). Five crop distributions were ranked. The first (A) was the observed crop distribution, then progressively, the percentage of risky crops was increased from 52 per cent in case A up to 85 per cent in case E. We assumed that, due to the large changes considered, and based on their indigenous knowledge from the

survey, farmers would rank them as follows: $A > B > C > D > E$. The ranking of the five alternatives by the three models matched the assumed farmers' preferences. Thus, this methodology seems to yield similar results even when using different measures of risk.

2.3 Use of a linear 'utility function' as a local approximation to the slope of the E-V frontier

The additive functional form has been elicited on the grounds of expected utility theory using techniques that involve the choice by the decision-maker between a certain outcome and a lottery (Anderson *et al.* 1977; Biswas 1997 and Hardaker *et al.* 1997).

Expected utility (EU) ranking, based only on the first two moments (mean and variance) of the expected return, was justified if some restrictions were placed on either the decision-maker's preferences or on the distribution of gross margins. Thus, if the utility function of the decision-maker was quadratic or all distributions were normal, the optimum EU would have been in the E-V efficient set (Levy and Markowitz 1979). Similar results can be found with mean standard deviation approximations (Tobin 1963 and Hawawani 1978). A less restrictive condition applies to the adoption of a two-moment decision model based on the location and scale parameters (Meyer 1987; Meyer and Rashe 1992). According to this condition, the ranking of the two-moment decision model will be consistent with the EU criterion if the random variables differ from one another only by location and scale parameters.[3] Furthermore, this condition is met by a variety of economic models.

The expected utility of a lottery $E[U(x)]$ derived from a quadratic utility function can be expressed as follows:

$$E[U(x)] = E(x) + b(\sigma^2 + \{E(x)\}^2) \qquad (3)$$

where b is normally expected to be negative (Robison and Barry 1987, p. 309). This, of course, is a linear additive function in the expected (mean) value, $E(x)$, and the variance, σ^2.

A quadratic utility function implies increasing absolute risk aversion (Robison and Barry 1987, p. 33), a strong assumption with weak theoretical support. However, Anderson *et al.* (1977, p. 93) claim that polynomial utility functions (particularly quadratic) are suitable for empirical analysis. Although polynomials are not monotonically increasing everywhere, they

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[3]All random variables Y_i differ from one another only by location and scale parameters if, for all X (X is a random variable obtained from one of the Y_i using the normalising transformation $X = (Y_i - \mu_i)_i/\sigma_i$), all Y_i are equal in distribution to $\mu_i + \sigma_i X$ (Meyer 1987).

argue from a practical point of view: 'empirical utility functions are estimated over a particular range of gains or losses, no one would recommend their use beyond that range'. They continue that, even when the true utility function is not quadratic, the quadratic utility function may not necessarily lead to error. While the utility of each risky prospect may be assessed incorrectly, the overall set of prospects may still be correctly ranked depending on how influential the higher moments are. Finally, even assuming that in most cases increasing absolute risk aversion is not acceptable, 'we can rationalise a risk-averse polynomial utility function for gains and losses as simply a local approximation to a concave risk-averse utility function for wealth' (Robison and Barry 1987, p. 33).

The other condition to ensure consistency between E-V analysis and EU maximisation relates to the statistical distribution of the outcomes. Samuelson (1970) showed that a risk-averse decision-maker will find the EU optimum in the E-V set as long as the distributions of returns are normal. Although this condition is rarely observed in practice, Tsiang (1972), using a different Taylor-series expansion than the one used by Levy and Markowitz (1979), proved that, even when the utility function is not quadratic and does not have normally distributed distributions, a two-moment decision model can be a good approximation to the true expected utility function when the risk remains small relative to the total wealth of the decision-maker.

However, as Robison and Hason (1997, p. 124) point out, the accuracy of the approximation of the E-V model to the EU model when none of the conditions are met (quadratic utility function, normally distributed returns or location–scale condition) has not been carefully examined. Yet, according to them, 'consistency between E-V and EU models may still be obtained because changes in skewness most often change the means and variances as well in ways that leave ranking between the two models consistent'.

2.4 Elicitation method for the utility functions

Sumpsi *et al.* (1993 and 1997) and Amador *et al.* (1998) propose a method for assessing a farmer's utility function, without direct interaction between the farmer and the researcher. They show how it is possible to elicit the farmer's utility function by observing only the actual crop distribution. We adopted this methodology to assess the utility function of a group of farmers. The steps were as follow:

1. Define mathematically each attribute as a function of a decision column vector (x), representing the area covered by each crop. In this paper we

consider: (i) the expected total gross margin, $\mathrm{E}(TGM) = \mathrm{x}' \cdot GM$, where GM is a vector of crop expected gross margins per hectare; and (ii) the variance (V) of the total gross margin, $V = \mathrm{x}' \cdot M \cdot \mathrm{x}$, where M is the variance–covariance matrix of a 5-year time series of gross margins.

2. For the average-sized farm in the stratum, calculating the optimum farm plan for each attribute is treated as the sole objective (maximisation of TGM and minimisation of V). This produces a two by two matrix, P, in which each element, f_{ij}, is the value of the ith objective when the jth objective is optimised. In order to avoid zero solutions when minimising risk, we restricted the solution to an assured minimum level of total gross margin per hectare (the hiring-out price of land).

3. Solve the following system of q (number of objectives) equations:

$$\sum_{j=1}^{q} w_j f_{ij} = f_i \quad i = 1, 2, \ldots, q; \text{ and } \sum_{j=1}^{q} w_j = 1 \qquad (4)$$

where f_{ij} is the corresponding element of the previous matrix and f_i is the value achieved for the ith objective according to the observed crop distribution. As not all farms in the stratum are equal in size, the elements f_1 and f_2 (observed TGM and V, respectively) must be calculated for the average-sized farm. For example, if the maximum TGM for an average 7.5 ha farm is 100 u., and the observed TGM value of a 9 ha farm is 125 u., then the f_i value in the equation is $(7.5/9) \cdot 125$ u. In the case of the variance, the ratio has to be the square $[(7.5/9)^2]$.

4. If the former system does not give a set of w (weights of each objective), the sum of positive and negative deviational variables is minimised:

$$\mathrm{Min} \sum_{i=1}^{q} \frac{n_i + p_i}{f_i}; \quad \text{subject to:}$$

$$\sum_{j=1}^{q} w_j f_{ij} + n_i - p_i = f_i \quad i = 1, 2, \ldots, q; \quad \sum_{j=1}^{q} w_j = 1 \qquad (5)$$

5. This procedure was applied to every one of the 65 farmers, and then the average weight of each objective was calculated for a relatively homogeneous group (small, medium and large farmers). Mathematically:

$$w_{ji} = \frac{\sum_{k=1}^{n_i} w_{jk}}{n_i} \qquad (6)$$

where w_{ji} is the weight that group i (small, medium and large farmers) places on the objective j (profit maximisation or risk minimisation), and w_{jk} is the weight attached by each farmer (k) to the same objective j within the group i. The number of farmers in each group (i) is denoted n_i.

Dyer (1977) has shown that the weights obtained in step 6 are consistent with the following separable and additive utility function: $u = \sum_{i=1}^{q} \frac{w_i}{k_i} f_i(x)$; where $f_i(x)$ is the mathematical formulation of the value placed on the ith attribute x, and k_i is a normalising factor (e.g. maximum value of the ith objective in the matrix P minus the minimum). In Appendix I the weighting of attributes is explained with a figure.

As the farming systems are reasonably homogeneous within groups, it is assumed that all members face the same set of activities and constraints. Thus, there is a single, unique optimum farm plan for the whole group for each given objective. The cropping patterns within each group that were obtained from the survey were sufficiently similar to justify the assumption of a common utility function for all members of the group.

3. Area of study

The El Bajo Guadalquivir community of irrigators is located in southern Spain in the Guadalquivir Valley. The crops grown in this irrigated area are shown in table 1.

This district has a typical Mediterranean climate with hot and dry summers and cold winters. In an average year there is 507 mm of rain, with an average temperature of 19.2°C. In the northern part of the district the soils are mainly Entisols, while in the south they are a mix of Entisols and Vertisols. The water consumption was 5311 m^3/ha in 1996 and 7275 m^3/ha in 1997.

Table 1 Crop distribution in El Bajo Guadalquivir (percentages and total hectarage)

	1995/1996	1996/1997	1997/1998
Cotton	37.8	59.0	51.4
Sunflower	26.9	12.4	15.3
Cereals (excluding rice)	11.2	12.1	19.6
Sugar beet	14.2	10.2	8.8
Vegetables	3.4	3.7	3.1
Others	4.2	1.3	0.9
Set aside	2.3	1.3	0.9
Total	100.0	100.0	100.0
Arable crops (hectares)	42 859	42 604	42 437
Total crops (hectares)	54 050	54 050	54 050

Source: Community of irrigators El Bajo Guadalquivir.

   Table 2 shows the land distribution in the community of irrigators and
the sampling quota assigned to each stratum. Farmers that had fewer than
5 ha were not considered. This is because farming provided only a minimal
part of their total income (the average farm size in this stratum was only
1.4 ha) and they would have been less likely to be involved in the water
market. The size of each quota was proportional to the number of farmers
within the group. To save travel costs, cluster sampling was used to select
the farmers to be interviewed in three different locations.

Table 2 Land distribution among farmers in 1998 and stratified sampling quotas

	< 5 ha	5–10 ha	10–20 ha	> 20 ha	Total
No. farmers	2662	689	1001	446	4 798
Total hectarage	3827	5289	12 473	29 712	51 301
Distribution of the 65 interviews	None	21	29	15	

Source: Community of irrigators El Bajo Guadalquivir.

4. The mathematical model

As already outlined in the methodology, we had to first define the objectives
to be considered. The survey revealed that most farmers considered the
maximisation of total gross margin and the minimisation of risk, assumed to
be represented by the variance of the total gross margin, to be their two main
objectives.[4]

   Estimates of expected total gross margin and its variance were obtained
from a time series over 5 years. The gross margin for each crop in this
time series was provided by an accounting firm in the area studied. The
farms in this database were similar, in terms of crop distributions and
production possibilities, to the farms in the communities of irrigators of
the area studied. The gross margins were double-checked with the results
from the survey.

   The gross margin's variance may have been overestimated due to
differences in conditions from farm to farm and its covariance may have
been underestimated, so we carried out an experiment to test for the effects of
smaller variances (30 per cent reduction) and greater covariances (30 per cent
increase) on the ranking ability of the utility function. Both models ranked
the distributions of five crops in the same way (although the utility values
were slightly different).

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   [4]An accounting firm provided panel data on 40 farms in the area of study over 5 years.
These data were used to model risk and to compare with the survey results.

There were two kinds of constraints in the model. First there were agricultural policy constraints, which had a quota for sugar beet and durum wheat. At least 10 per cent of COP (cereals, oilseeds and protein crops) were set aside. Second, there were agronomic constraints which prevented the sowing of wheat and sunflower over two consecutive years on the same plot. The crop distribution of each farmer was used to obtain the weights attached by the farmers to the total gross margin and risk objectives.

Table 3 shows the average farm size and the extreme values of the expected total gross margin and the variance in each stratum. The results of the model, using the average weights for the two attributes considered, are also presented.

Table 3 Weights attached to each attribute in percentage and absolute terms for each stratum

		Stratum		
		Small farmers (5–10 ha)	Medium farmers (10–20 ha)	Large farmers (> 20 ha)
	Average farm size (ha)	8.1	13.5	53.5
Extreme values	Max TGM[†] (10^3 Ptas/ha)	1 613	2 571	9 668
	Min TGM[†] (10^3 Ptas/ha)	738	1 548	5 856
	Max variance	243 681	586 164	9 009 064
	Min variance	23 065	41 168	1 135 648
Weights (%)	Maximisation of TGM[†]	86	68	61
	Minimisation of variance	14	32	39
Normalised weights	Maximisation of TGM $= a$	0.09829*	0.06647	0.01600
	Minimisation of variance $= b$	0.00006	0.00006	0.00000
	Slope $= b/a$	0.00065	0.00088	0.00031

Source: own estimates.
*To calculate: $86/(1613-738) = 0.09829$.
[†]TGM, total gross margin.

In considering the mean variance preference function

$$U = a \cdot TGM - b \cdot V, \tag{8}$$

$2 \cdot b/a$ is a local measure of absolute risk aversion (Chavas and Pope 1982; Coyle 1992 and 1999). The absolute risk aversion coefficients in increasing order of farm size were 0.0013, 0.0018 and 0.0006. There was no clear

relationship between farm size and the measure of risk aversion. These mixed results coincide with other studies (Bond and Wonder 1980; Hamal and Anderson 1982).

The utility functions were maximised in order to simulate farmers' responses to changes in the price of water. An increase in the water price reduced the gross margin of each crop according to the level of application. To allow sowing without irrigation (wheat and sunflowers were watered only by rain), new activities were included in the model with new gross margins.

The policy changes affected the cost structure and therefore the gross margins. However, subtracting a constant (the water cost) from each column of gross margins in the time series matrix (crops in columns) did not change the variance–covariance matrix, therefore the old matrix could have been used. This would not have applied for major policy changes and long run analysis, where prices and yields would have been affected.

5. Validation of the model

Validation of the estimated utility functions was based on two procedures. First, assuming that farmers produce at a point close to their maximum utility, the optimum plan for each stratum should not differ greatly from the observed crop distribution. This was found to be the case in general (see table 4). The comparison of model predictions with real system outputs is, in practice, a common procedure to validate models (Rigby and Young 1996; Qureshi *et al.* 1999).

Second, the ranking of alternative crop production activities based on the estimated utility function was compared with the farmers' own preference ranking, and found to be identical.

Although the first validation procedure may have suffered from a circular argument (the utility functions are derived from farmers' behaviour and then validated by reproducing their behaviour), the two validation procedures together supported our confidence in the use of the estimated utility functions to model the farmers' decision-making process.

6. Elicitation of water demand curves

The farmers' responses to water price increases was simulated by using the three elicited utility functions after reducing the crop gross margins according to water prices and crop water use. The initial situation (price $= 0$ Ptas/m^3) was compared with progressive price increases for water that were included in the models as variable costs, which reduced the crop gross margins. Table 5 summarises the derived water demand for each stratum.

Table 4 Observed and simulated crop distribution by stratum (percentages)

	Small farmers (5–10 ha)			Medium farmers (10–20 ha)			Large farmers (> 20 ha)		
	Observed	Max U	Absolute deviation	Observed	Max U	Absolute deviation	Observed	Max U	Absolute deviation
Cotton	72.5	70.2	2.3	59.9	53.8	6.1	43.5	44.3	0.8
Maize	10.2	9.9	0.3	13.0	17.8	4.8	19.6	18.3	1.3
Sunflower	2.5	0.6	1.9	12.8	12.6	0.2	18.5	17.5	1.0
Sugar beet	3.2	3.2	0.0	8.0	8.0	0.0	10.1	10.1	0.0
Durum wheat	1.0	0.0	1.0	2.3	2.3	0.0	4.9	4.9	0.0
Potatoes	3.5	4.1	0.6	2.0	3.7	1.7	1.2	2.8	1.6
Common wheat	0.1	0.0	0.1	0.3	0.0	0.3	0.7	0.9	0.2
Vegetables	10.5	16.2	5.1	3.7	5.5	0.1	1.7	3.2	0.1
Set aside	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.8	0.2
Total	100.0	100.0	11.3	100.0	100.0	13.2	100.0	100.0	5.2

Source: own survey and simulations.

Table 5 Water demand for small, medium and large farm-sized farmers

Price (Ptas/m³)	Small farmers		Medium farmers		Large farmers		Total demand	
	SFD (m³/ha)	SFTD (10⁶ m³)	MFD (m³/ha)	MFTD (10⁶ m³)	LFD (m³/ha)	LFTD (10⁶ m³)	m³/ha	10⁶ m³
0	4913	25.98	4453	55.54	3997	118.77	4219	200.29
5	4778	25.27	3815	47.59	3445	102.37	3691	175.23
10	4518	23.90	3178	39.64	2937	87.26	3176	150.79
15	3531	18.68	2712	33.83	2499	74.26	2670	126.77
20	1920	10.15	1937	24.17	1802	53.53	1851	87.85
25	609	3.22	578	7.21	640	19.02	621	29.46
30	534	2.82	406	5.06	388	11.54	409	19.42
35	458	2.42	139	1.73	71	2.10	132	6.25
40	284	1.50	114	1.42	59	1.74	98	4.67

Source: own estimates.
LFD, large farmers' demand; LFTD, large farmers' total demand; MFD, medium farmers' demand; MFTD, medium farmers' total demand; SFD, small farmers' demand; SFTD, small farmers' total demand.

As can be seen, the consumption of water per hectare (SFD, small farmer demand; MFD, medium farmer demand; LFD, large farmer demand) decreased, in general, as farm size increased. Total quantity demanded per hectare was the sum of the group mean levels of water consumption per hectare, weighted by the stratum size (in hectares) as a percentage of the total area. Thus, Total $D = (SFD \cdot 5289 + MFD \cdot 12\,473 + LFD \cdot 29\,712)/47\,474$.

Figure 1 shows the three demand curves. Although they differ in shape, they follow a similar pattern, as reported in other studies (Wahl 1989; Garrido 1998; Sumpsi *et al.* 1998; Gómez-Limón and Berbel 2000).

To analyse the differences in the elasticity of demand between curves, table 6 presents the arc elasticity of demand for each price interval. For a price lower than 10 Ptas/m³ the curves are rather inelastic, implying that farmers do not change their cropping pattern significantly. Only for higher prices does the elasticity increase.

7. Results of the water market simulation

7.1 Water trade

In the simulation we simplified the market by considering only three economic agents: small, medium and large farmers. Every agent bought or sold according to the utility derived from each unit of water at a given price. Unlike the assumptions of neoclassical theory, the use of the resource was not directly determined by its productivity but by its utility.
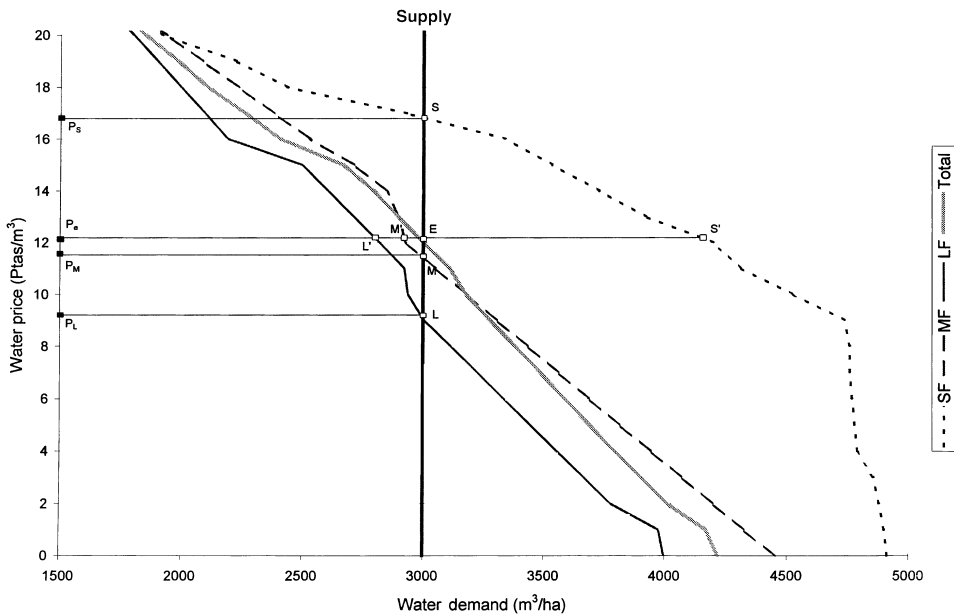
Figure 1 Water demand curve for each stratum

In the previous section we have presented the derived demand curve for each group of farmers (see figure 1). The supply of water was exogenously determined by the water authorities. The amount supplied per hectare was largely determined by the water stock in the reservoirs. Thus, in the short run, water supply was completely inelastic. This amount was distributed on a per hectare basis.

In the absence of a local water market, the quantity demanded for each group was indicated by S, M and L (see figure 1), for small, medium and large farmers, respectively. These points represented the marginal utility of water for each type of farmer, measured in monetary terms by P_S, P_M and P_L. The marginal utility differences provided incentives for water trade among the groups.

Given that the maximum aggregated quantity demanded for a zero water price was 4218 m^3/ha, in a year with a normal supply (greater than 5000 m^3/ha), no trade in water would have occurred (there was an excess of supply). However, due to cyclical droughts, a supply of 3000 m^3/ha, or even lower, was a more likely scenario. In this particular case (supply of 3000 m^3/ha), the marginal utility, reflected in the willingness to pay, for small, medium and large farmers was 16.8, 11.4 and 9.1 Ptas/m^3, respectively. The equilibrium was at the price–quantity combination (P_E, Q_{3000}), at a price of approximately 12 Ptas/m^3. Thus, because $P_E > P_M, P_L$ and $P_E < P_S$, medium and

Table 6 Price elasticity of demand for each interval

Price ranges (Ptas/m^3)	Small farmers' demand	Medium farmers' demand	Large farmers' demand	Total demand
0–5	−0.01	−0.08	−0.07	−0.07
5–10	−0.08	−0.27	−0.24	−0.22
10–15	−0.61	−0.40	−0.40	−0.43
15–20	−2.07	−1.17	−1.14	−1.27
20–25	−4.66	−4.86	−4.28	−4.48
25–30	−0.73	−1.93	−2.70	−2.26
30–35	−0.99	−6.37	−9.00	−6.67
35–40	−3.51	−1.50	−1.38	−2.18

Source: own estimates.

large farmers transferred water to small farmers; that is, the marginal utility of water for small farmers was greater than the price. The water trade would take place until the marginal utilities of all groups were equal (note that transaction costs are not considered in this analysis).

At the equilibrium price, P_E, small farmers moved from S to S', and were willing to pay for an additional amount of water measured by the distance ES'. The consumers' surplus for the small farmers increased by the area P_SSS'P_E. Accordingly, the equilibrium for medium and large farmers changed to M' and L', respectively. These two groups offered quantities of water to small farmers, measured by EM' and EL'. The losses of consumer surplus for medium and large farmers are defined by the areas P_MMM'P_E and P_LLL'P_E, respectively. The extra income from the water sale offset these surplus reductions.

The following table shows estimates of water transfers for several supply scenarios (at different equilibrium prices).

From the previous results, it follows that, for most price levels, small and medium farmers buy water. For most levels of supply, the volume of traded water is very small compared with the total amount in the market. Only when the quantity supplied is less than 400 m^3/ha (in an average year the supply is 6000 m^3/ha), are the transfers greater than 5 per cent of the total amount of water used in the community of irrigators.

Although there is an income transfer from small and medium farmers to large ones, this should not pose any problems of social injustice, as the groups that buy water do it in order to increase their utility (Rawls 1971).

7.2 Economic impact

The economic analysis cannot be limited to the financial transfers. To assess the whole economic impact of the introduction of local water markets, it is

Table 7 Water transfers in quantity and monetary terms for small (SF), medium (MF) and large farmers (LF)

Price Ptas/m³	D m³/ha	SF sales m³/ha	SF sales 10⁶ m³	MF sales m³/ha	MF sales 10⁶ m³	LF sales m³/ha	LF sales 10⁶ m³	Total trade 10⁶ m³	Trade (%/total)	Trade value 10⁶ Ptas
0	4219	0	0.00	0	0.00	0	0.00	0.00	0.00	0.00
5	3691	−1087	−5.75	−124	−1.55	246	7.30	7.30	4.16	36.49
10	3176	−1342	−7.10	−2	−0.02	239	7.12	7.12	4.72	71.16
15	2670	−861	−4.55	−42	−0.52	171	5.08	5.08	4.01	76.16
20	1851	−69	−0.37	−87	−1.08	49	1.45	1.45	1.65	29.01
25	621	11	0.06	42	0.53	−20	−0.59	0.59	1.99	14.64
30	409	−124	−0.66	3	0.04	21	0.62	0.66	3.39	19.75
35	132	−326	−1.73	−7	−0.09	61	1.82	1.82	29.06	63.56
40	98	−186	−0.98	−15	−0.19	40	1.18	1.18	25.22	47.07

Source: own estimates.
Negative sales imply buyer of water.

necessary to estimate the variations in gross margin due to selling/buying water.

The introduction of a water market involves, as was explained earlier, new equilibrium points for the different operating agents (S to S′, M to M′ and L to L′). Thus, those farmers who sell water change their crop plans toward less water-demanding crops with lower gross margins. The reduction of total gross margin is partially offset by the income from selling water. For buyers, the situation is the opposite. They move toward crops with higher gross margins, although they have to pay for the extra water use. Hence, both elements need to be taken into account in order to assess the overall economic impact (see table 8).

For example, with a supply of 4000 m^3, the market equilibrium price is fixed at 2.09 Ptas/m^3. At this price, small farmers would buy water at a cost of 1833 Ptas/ha to increase their total gross margin to 13 645 Ptas/ha (net result $= 13\,645 - 1833 = 11\,812$ Ptas). This is due to the higher percentage of vegetables on small (and medium) farms, crops with a higher expected gross margin and higher water needs. In this sense, the optimum resource allocation resulting from the water trade implies a positive benefit for all economic agents: small and medium farmers experience a rise in income, and large farmers lose less than they would without the trade.

From the previous results, we can see that trade in water is of most benefit to small (and medium) farmers, despite the increased cost of water. The benefit ranged from 235 to 16 794 Ptas/ha, representing an increase in the average total gross margin of 0.2–14.0 per cent.

In contrast, for large farmers the income from selling water does not offset the reduction in total gross margin. This can be explained by their utility-maximising behaviour. Thus, although the total gross margin is reduced, so too is the variance (due to a shift toward the adoption of less risky crops), with an overall increase in utility level.

The aggregate impact on the whole irrigated area (see last column in table 8) is positive for supplies greater than 2000 m^3/ha. However, the maximum gain (some 52 million Ptas, or 312 000 Euros) is insignificant considering the size of the area analysed (50 000 ha). For a supply less than 2000 m^3/ha the overall impact on the community is negative.

7.3 Social impact

Table 9 presents the social impact measured in terms of the demand for farm labour. The aggregate result shows an increase in the employment of hired labour following the introduction of the water market. Thus, raising the opportunity cost of water shifts the crop distribution towards crops with a higher gross margin to water consumption ratio (0.056 for vegetables, 0.048

Table 8 Changes (Δ) in farm total gross margin and income from selling/buying water

Supply m³/ha	Price Ptas/m³	Small farmers (Ptas/ha)			Medium farmers (Ptas/ha)			Large farmers (Ptas/ha)			Total 10⁶ Ptas
		Δ TGM	Sales income	Total	Δ TGM	Sales income	Total	Δ TGM	Sales income	Total	
4000	2.09	13 645	−1 833	11 812	2845	−389	2456	−3105	468	−2637	14.76
3800	3.95	18 855	−3 920	14 935	2369	−588	1781	−2596	906	−1691	50.97
3600	5.88	23 084	−6 865	16 218	1712	−607	1105	−3717	1421	−2296	31.35
3400	7.82	27 391	−10 597	16 794	967	−439	528	−4126	1999	−2127	32.20
3000	12.00	29 737	−14 322	15 415	−1328	879	−448	−2891	2079	−811	51.83
2500	15.65	18 007	−14 162	3 845	1998	−1472	526	−3609	3013	−596	9.20
2000	18.88	5 800	−4 718	1 082	2385	−1950	436	−2017	1525	−492	−3.45
1000	23.70	4 444	−4 208	235	4002	−3771	231	−2445	2201	−244	−3.13

Source: own estimates.

Table 9 Changes (Δ) in total farm employment from selling/buying water

Supply (m³/ha)	Price (Ptas/m³)	Small farmers Δ employment (man−day/ha)	Medium farmers Δ employment (man−day/ha)	Large farmers Δ employment (man−day/ha)	Total Δ employment (10³ man−day)
4000	2.09	1.31	0.26	−0.25	2.66
3800	3.95	1.98	0.21	−0.41	0.80
3600	5.88	2.48	0.15	−0.27	6.81
3400	7.82	2.96	0.08	−0.29	8.09
3000	12.00	2.77	−0.10	−0.12	10.02
2500	15.65	1.36	0.17	−0.19	3.77
2000	18.88	0.67	0.21	−0.19	0.43
1000	23.70	0.33	0.22	−0.10	1.49

Source: own estimates.

for cotton, 0.047 for potatoes, 0.043 for sunflowers). These crops are more labour-intensive (50 men/day per ha for vegetables, 12 for cotton, 2.5 for sunflowers).

The overall impact is relatively unimportant as the largest increment in farm employment (corresponds with a supply of 3000 m³/ha) is equivalent to 40 full-time workers, a small figure for a 50000 ha agricultural area.

8. Conclusions

The main conclusions that can be drawn from this study are:

1. Multi-attribute utility functions have proven to be a useful tool for simulating farmers' responses to policy changes, such as the introduction of water markets.
2. In a community of irrigators in southern Spain, a water market was likely to operate for a water supply of less than 4218 m³/ha, a circumstance only feasible in drought years.
3. In this hypothetical market, small farmers (between 5 and 10 ha) and medium farmers (10–20 ha) would be the buyers and large farmers (more than 20 ha) the sellers. This simulation implies the transfer of water from large to small farmers, and a corresponding monetary transfer between groups.
4. Small and medium farmers would benefit the most from a water market. Small farmers could increase their total gross margin by up to 14 per cent, although the risk involved was greater (due to a higher percentage of vegetables).
5. The social impact was limited in terms of farm employment. There was a slight overall increase in farm employment under the water market scenario.

The conclusions drawn in this study are limited because we did not consider transaction costs. Furthermore, other alternative uses of water (leisure activities, urban consumption, etc.) were omitted from the analysis. However, this methodology may be considered as a starting point for the simulation of policy scenarios for local water markets.

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Appendix I. Calculation of weight of each attribute according to farm position in expected value variance (E-V) space