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Evaluation of markets for irrigation water in the internal river basins of Catalonia, Spain

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Abstract

Irrigated agriculture has come under close scrutiny in Europe recently because of its high share of total water consumption and its apparent inefficiency. Several water policies have been advocated, in particular the use of economic instruments such as water markets. This paper simulates the impact of a policy based upon water markets on agricultural production in the internal river basins of Catalonia (Spain). This zone presents certain particularities that make it very interesting to study: competition between sectors for the resource (agriculture-urban consumption-recreational uses), recent periods of resource insufficiency and conflicts between irrigators as a result of the measures taken by the hydraulic administration in drought situations. The results show that these markets would guarantee an optimal reassignment of the resource in situations of supply restrictions, and although compared to the situation without markets they would not mean higher economic profits for the irrigators, they could prevent conflicts between them. Nevertheless, doubts exist about their acceptance by irrigators.

Additional key words: irrigated agriculture, multicriteria decision models.

Resumen

Evaluación de mercados de aguas de riego en las cuencas internas de Cataluña (España)

Últimamente se ha puesto en duda el papel económico del regadío en Europa, debido al elevado consumo de agua que representa, así como a su aparente baja eficiencia de uso. Al mismo tiempo, las políticas tradicionales de gestión de aguas están en entredicho, surgiendo nuevos planteamientos, destacando entre ellos el uso de instrumentos económicos como los mercados de aguas. Este artículo analiza el impacto sobre la producción agrícola de la instauración de mercados de aguas en un área de riego comunitario ubicada en las cuencas internas de Cataluña (España). Esta zona presenta ciertas particularidades que hacen que su estudio sea especialmente interesante: se trata de un área con una elevada competencia intersectorial por el uso del recurso (agricultura-consumo urbano-usos recreativos), recientes periodos de insuficiencia en el suministro y conflictos entre regantes como resultado de las medidas tomadas por la administración hidráulica en caso de sequía. Los resultados obtenidos muestran que los mercados garantizan una reasignación óptima del recurso en situaciones de restricción del suministro, y aunque globalmente no generan una ganancia económica muy elevada respecto a la situación sin mercado, sí podrían evitar conflictos entre regantes. Sin embargo, existen dudas sobre su aceptación práctica por parte de dichos regantes.

Palabras clave adicionales: agricultura de regadío, modelos de decisión multicriterio.

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Introduction

Agriculture is not only the greatest water user of the world in terms of volume, it is also a relatively low value, low efficiency and highly subsidised user (FAO, 1995). In Europe, irrigated land doubled from 1975 to 1995 and in Spain, the European country with the largest area of irrigated land, it already exceeds 3,500,000 ha (FAO, 2004).

Numerous authors point to the importance of economic instruments in the management of water to improve water use efficiency (Grimble, 1999). In this same sense, water policy has become an important issue during the past few years, and political consensus has moved in the direction of modernising legislation. In 1995 the European Commission and Parliament initiated the process of developing a Common Policy on Water, as part of Article 130R of the Treaty of the Union that empowers the European Commission to protect the environment. Many issues have been barriers to early agreement, but one of the most difficult has probably been Article 9 in the first drafts of the proposal, which originally obliged EU members to charge the full cost of water to users. The final result has been Directive 2000/60/CE (OJ, 2000), the «Water Framework Directive» (WFD). This Directive establishes that EU members should try to recover all water service costs, including environmental costs, in accordance with the «polluter pays principle», aimed at social and environmental sustainability. This is an example of the importance of economic instruments to improve water management in Europe.

Also, new water laws appearing in Spain recognised the importance of economic instruments. In this country, ownership of water resources belongs to the State, but the right to use the water may be obtained through government concessions granted by the regional water authorities. The Consolidated text of the Water Act (Royal Decree 1/2001, 20th July 2001) legalises water markets in Spanish territory, but it imposes a series of restrictions. One of the most important is that water transfers must be made from one use to another of the same category or of a higher category according to the order of preference established in the Hydrological Plan of the corresponding basin, which generally is: urban supply; agriculture; electrical energy production; industry; aquaculture; recreational uses; navigation and water transport; and other uses.

Considering these restrictions, the law offers new possibilities in water management using market mechanisms to improve the allocation efficiency.

There is no doubt about the seriousness of the application of a water pricing policy for the future of irrigated lands, since it will presumably have a negative influence on their competitiveness and the surrounding socio-economic conditions (Gómez-Limón and Berbel, 2000), although in certain cases there are studies that suggest the opposite (Doppler *et al*., 2002). A complete revision of the water demand policies (including studies and experiences concerning pricing policies and water markets) can be consulted in Sumpsi *et al*. (1998, Chapter 3).

Also, the effects of applying economic instruments to water management will vary according to the specific characteristics of the zone where these measures are applied. The WFD recognises the importance of the particularities of each zone and requires each state to carry out an economic study of the use of the water in each hydrographic area.

The objective of the present work was to study the viability of agricultural water markets to improve irrigation water management in the internal river basins of Catalonia at two levels: intra-irrigator community and inter-irrigator community. It is desirable to analyse this improvement with respect to the present system of water allocation in conditions of insufficient water provision.

Case study

This study has been carried out in the six main irrigation communities of the Muga and Ter Rivers, which form the third most important irrigation zone of Catalonia (after the *Zona de Ponent* in Lleida and the *Terres de l'Ebre* in Tarragona), and the most important zone of the internal river basins. An irrigation community is a grouping of all the owners of a same irrigable zone, united by law for the independent and common administration of public waters. Figure 1 shows the location of the studied communities of irrigators.

The analysis of this zone is especially interesting because it has not been the object of previous studies of this nature, and it is an area with particular problems: strong inter-sectoral competition for the use of the resource and the existence of latent conflict between irrigators in drought situations.

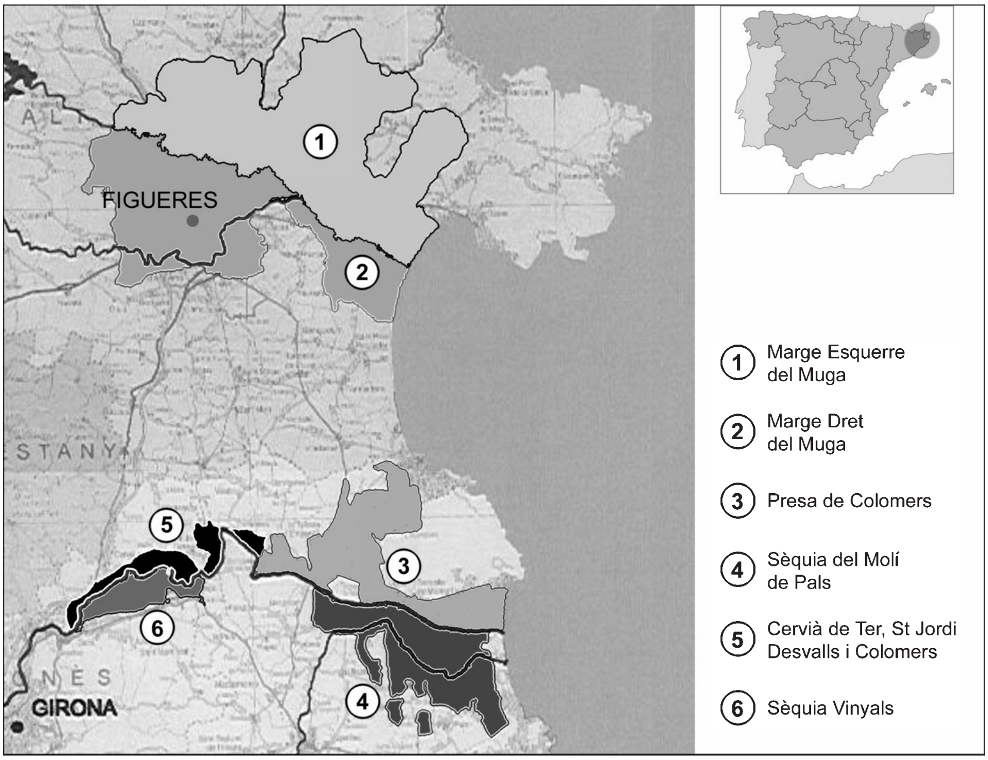

Figure 1. Location of the six communities of irrigators studied.

Currently, the annual water consumption in the zone of study is 246.3 hm^3 $year^{-1}$. This consumption is distributed between sectors in the following way: 70% corresponds to the agricultural sector (including the needs of golf courses), 20% to domestic demand and 10% to the industrial sector (DMA, 2002).

Domestic demand has a seasonal character, caused by consumption resulting from tourism and concentrated during the summer season: the average monthly demand increases by 51% during the peak period (July). The interest in completely satisfying this demand is obvious: tourism provides around 10% of the Gross Domestic Product of Catalonia. Specifically, tourism on the Costa Brava (in the same zone as the case study) generated 2,940.6 million euros in 2002, 28% of the total generated by tourism for all of Catalonia (Oliver, 2002).

In this irrigated area the agricultural sector is the largest water consumer. For this sector, as well as the urban sector, problems of seasonal variation are focused on the summer months. Another problem related to this use is ground water pollution by nitrates. In 1998 the zone was declared vulnerable to nitrates and some of the potentially polluting husbandry practices were restricted (DOGC, 1998).

The six irrigation communities have been divided into three groups on the basis of similarities in technical characteristics and geographical proximity: the Muga, the Lower Ter and the Middle Ter. In these zones the main cultures are corn, sunflower, other grain cereals, alfalfa, fruit trees and sorghum. Other important cultures are poplars and ornamental trees in the Middle Ter, and rice in the Lower Ter. Table 1 summarises the main characteristics of these groups of communities. Common characteristics are the organization of irrigation by turns, the predominance of gravity irrigation (with the limited presence of drip irrigation in fruit trees and sprinkle irrigation in cereals), and the existence of important problems concerning the state of irrigation water transport infrastructures and the lack of resources to repair them.

In addition, there are important recreational uses of water, such as golf. In the studied zone, there are three golf courses and one pitch and putt. According to Priestley and Sabí (1993), the average water consumption for an 18 hole golf course in Catalonia is

Table 1. Characteristics of the groups of communities of irrigators studied

Groups of communities	Muga	Middle Ter	Lower Ter
Communities	*Marge Esquerre del Muga* and *Marge Dret del Muga*	*Cervià de Ter, Sant Jordi Desvalls i Colomers* and *Sèquia Vinyals*	*Presa de Colomers* and *Sèquia del Molí de Pals*
Surface (ha)	5,220	1,500	7,100
Number of irrigators	1,200	625	2,192
Type of water tariff [1]	By irrigable surface	By irrigated surface (*Cervià de Ter, Sant Jordi Desvalls i Colomers*) or by irrigable surface (*Sèquia Vinyals*)	By irrigated surface (*Sèquia del Molí de Pals*) or by irrigable surface (*Presa de Colomers*)
Tariff value (€ ha^{-1})	25-42	54-120	6-87
Water provision	Depending on the availability; 26 hm^3 in a year without restriction (1997)	Concession of 2,038 L s^{-1} throughout the year	Concession March to October, variable according to the month of the year
Water restrictions	Frequent; in 1999 no water was distributed	Infrequent, but in 1999 there were restrictions	Infrequent

[1] Water tariff by irrigable surface means that the irrigators pay according to the land surface capable of being irrigated, while by irrigated surface means that they pay according to the actual irrigated surface.

325,976 m^3 $year^{-1}$, a consumption comparable with that of a town of 10,000 inhabitants. The current tendency of the Administration is to promote this irrigation with treated waste water.

In the internal river basins of Catalonia the responsibility for hydraulic management is in the hands of the ACA (Catalan Water Agency) of the Catalan Government. In the years in which there have been resource shortage problems (1999, 2000, 2002) the ACA has adopted measures to limit the amount of water used in each hydrographic river basin, as well as the allocations destined to certain specific uses, always giving priority to urban supply. The procedure has been one of decree promulgation, with consequences for the agricultural and recreational sectors.

In the most extreme case, the application of these restrictions imposed on irrigated agricultural land meant that in 1999, in the zone of the Muga, there was practically no irrigation. Within the agricultural sector there exists a preferential treatment for fruit trees, based on the idea that «the adopted measures cannot produce irreversible damages in the permanent fruit cultures». The justification is that they are cultures with high establishment costs and a long period of amortization. Nevertheless, this situation has created fierce controversies among irrigators: there have been complaints about fruit producers irrigating in excess, not only to ensure the survival of their groves but also to ensure profitable production, while neighbouring cereal producers lose their harvests by not being able to irrigate. Criticisms have also come from other sectors, such as the producers of ornamental ligneous plants, which are also perennial cultures with high establishment costs.

The year 2005 has also been a drought year, and the previously commented problems continue.

Methodology

Field data have been used to create a model to evaluate the result of implementing water markets at both the intra-community and inter-community levels. The method chosen is based on a demand simulation for the different irrigating groups by means of a multi-criteria analysis.

Obtaining field data

The field data were obtained through face-to-face interviews with a sample of irrigators (170 farmers). The total farmed surface of the sample was 25% of the irrigable surface area of the studied zone. The sampling was done by irrigator communities and by quotas within each community. The factor used in the definition of the quotas was the farmer's surface area. The farms of the sample were chosen to reproduce the same distribution of farm surface areas existing in the population. Farms smaller than one hectare were excluded. Information was requested from the irrigators about their production decisions and their opinions of water markets. The complete questionnaire can be consulted in Pujol (2002).

Classification of the irrigators

The irrigators' production decisions (crop surfaces) were analysed, similarities were searched for and the irrigators were grouped accordingly. Cluster analysis was applied using Ward's algorithm (Ward, 1963). Ward's method uses an analysis of variance approach to evaluate the distances between clusters. Cluster membership is assessed by calculating the total sum of squared deviations from the mean of a cluster. The criterion for fusion is that it should produce the smallest possible increase in the error sum of squares. This involves finding the mean of each cluster and the distance to each object contained in each cluster, squaring these distances and summing the squared distances for all the objects in all the clusters. In general, this method is regarded as very efficient; however, it tends to create small sized clusters (Jain *et al*., 1999). The analysis was made separately for each one of the three groups of irrigation communities. The model was created based on clusters obtained from the decisions on production, assuming that the irrigators who make different decisions about production have different objectives. Based on productive orientation and location, eleven types of irrigators have been identified (Table 2). The type names are self-explanatory: 'corn' refers to farms that specialise in extensive crops in general, with a high percentage of corn, while 'mixed' implies that there is no predominant crop, with farms cultivating cereals, sunflowers, and even a small proportion of fruit trees. 'Livestock' means that fodder crops for animal feeding cover a large part of the cultivated area. Finally, 'fruit' refers to farms with a high proportion of orchard cultivation (apples, primarily), while 'ornamental' farms cultivate only garden trees and plants.

The clusters obtained are consistent with the empirically observed results: clusters define groups of farmers with appreciably different behaviours.

Obtaining the utility function

The next phase was to obtain the utility function. In order to model the irrigators' decision-making

Table 2. Surrogate utility function weights by farm type and location

Zone	Productive orientation	Weight for criteria		
		GM maximisation	Labour minimisation	Risk minimisation
Muga	Corn	0.99833	0.00078	0.00089
	Livestock	1	0	0
	Mixed	0.92985	0	0.07015
Lower Ter	Mixed	0.92154	0	0.07846
	Fruit	0.99796	0	0.00204
	Livestock	1	0	0
	Corn	1	0	0
Middle Ter	Corn	1	0	0
	Mixed	0.7635	0.2365	0
	Livestock	1	0	0
	Ornamental	1	0	0

process, it was necessary to either adopt a classic approach, supposing that the irrigators optimise a single objective (i.e. profit), or to assume that they consider several objectives simultaneously. Von Neumann and Morgenstern (1944) first explained economic acts as not only the result of profit (as a deterministic variable) but also of risk (expected utility theory). Many other authors have also supported the multiplicity of objectives in agricultural activities (see Romero and Rehman, 2003).

One approach to the multi-criteria decision-making paradigm is the multi-attribute utility theory (MAUT). It is often argued that MAUT has the soundest theoretical structure of all the multi-criteria techniques (Ballestero and Romero, 1998). In MAUT, the utility of an alternative option (i) is captured in a quantitative way via a utility function:

$$U = U_i\ (r_{i1}, r_{i2}, ..., r_{iq}) = f\{u_1\ (r_{i1}), u_2\ (r_{i2}), ..., u_q\ (r_{iq})\}$$
$$= 1, ..., \text{n}; \quad j = 1, ..., \text{q}$$

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

If these attributes are mutually utility-independent, the formulation becomes, in simple additive form:

$$U_i = \sum_{j=1}^{q} w_j u_j (r_{ij}) \qquad [1]$$

where w_j is the weight of attribute j, and it is often assumed that $0 \leq w_j \leq 1$ and $\Sigma\ w_j = 1$ (Keeney, 1974).

The additive utility function has been widely used to model farmers' decisions when one of the criteria involved is uncertainty. The ranking of alternatives is obtained by adding contributions from each attribute. Since attributes are measured in terms of different units, normalisation is required to permit addition. The weighting of each attribute expresses its relative importance.

Fishburn (1982) presents the mathematical requirements for assuming an additive function. These conditions are restrictive, but 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 very much more complicated non-linear forms, while remaining far easier to use and understand». Although the assumption of linearity of the individual attribute utility function is rather strong, the validation of the model supports this decision.

The ability to simulate real decision-makers' preferences is based on the estimation of relative weightings. The methodology selected is weighted goal programming, which avoids interaction with farmers and in which the utility function is elicited on the basis of the revealed preferences implicit in the actual values of decision variables (i.e. the crop plan in farm management). Previous uses of this methodology can be found in Amador *et al*. (1998), Berbel and Rodríguez-Ocaña (1998), Arriaza *et al*. (2002).

The method may be summarised as follows:

a) Each attribute is defined as a mathematical function (f_j) of an alternative, i.e., a concrete combination value of the decision variables x (e.g. crop area); $f_j = f_j(x)$. These attributes are proposed *a priori* as the most relevant decision criteria used by farmers (objectives).

b) The pay-off matrix is calculated, where $f_{jj'}$ is the value of the *j-th* objective when the *j'-th* objective is optimised. The main diagonal is the 'ideal' point defined by the individually obtained optimum (f_{*j}), the value of the *j-th* objective when it is optimised.

$$\begin{pmatrix} f_{*1} & \dots & f_{1j'} & \dots & f_{1q} \\ \dots & \dots & \dots & \dots & \dots \\ f_{j1} & \dots & f_{*j} & \dots & f_{jq} \\ \dots & \dots & \dots & \dots & \dots \\ f_{q1} & \dots & f_{qj'} & \dots & f_{*q} \end{pmatrix}$$

c) The following q+1 system of equations is solved

$$\sum_{j'=1}^{q} w_{j'} f_{jj'} = f_j \qquad j = 1,2,...,q \text{ and } \sum_{j'=1}^{q} w_{j'} = 1 \qquad [2]$$

where q is the number of *a priori* relevant objectives, $w_{i'}$ are the weights attached to each objective (the solution), $f_{jj'}$ are the elements of the pay-off matrix, and f_j the real values reached in the observed behaviour of farmers, as obtained by direct observation.

d) Normally, there is not an exact solution to system [2] and it is therefore necessary to solve a problem by minimising the sum of deviational variables that find the closest set of weights.

$$\text{Min} \sum_{j=1}^{q} \frac{n_j + p_j}{f_j} \text{ subject to :} \qquad [3]$$

$$\sum_{j'=1}^{q} w_{j'} f_{jj'} + n_j - p_j = f_j \;\; j = 1, 2, ..., q \text{ and } \sum_{j'=1}^{q} w_{j'} = 1$$

where n_j and p_j are negative and positive deviations, respectively.

Dyer (1977) demonstrates that the weights obtained in [3] are consistent with the following separable and additive utility function.

$$U = \sum_{j=1}^{q} \frac{w_j}{k_j} f_j(x)$$

where k_j is a normalising factor (e.g. the difference between maximum and minimum values for objective j in the pay-off matrix).

Following the multi-criteria methodology, a model for each farm type and irrigation community group has been built.

The crop plan selected will determine changes in certain attributes of the system. Attributes are relevant functions that are deduced from the decision variables, but as has been mentioned before, 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 (they consider the cost of the fertiliser to be important, not the amount). Attributes to which decision makers assign a desired direction of improvement are considered to be objectives. The main elements of the mathematical model used are:

a) Variables:

Each farmer member of the irrigation community group has a set of variables X_i (crops), as described in the previous section. These are the decision variables that may assume any value belonging to the feasible set.

b) Objectives:

In order to obtain the utility function, three objectives must be regarded as belonging to the farmer's decision-making process:

- *Profit maximisation*, estimated as the maximum attainable expected gross margin (GM).
- *Risk minimisation*, measured as the minimisation of total absolute deviation (MOTAD), proposed by Hazell (1971) (see also Watts *et al*., 1984) as a linear estimator of variance.
- *Minimisation of labour inputs*, in terms of hours of labour required (LAB).

The first two objectives are classic in agricultural economics: a large number of studies quote their importance in farm decision-making. The third has been included as a consequence of our field research and is regarded as *a priori* relevant by experts and farmers.

c) Constraints:

- *Land constraint*. The sum of all crops must be equal to the area assigned to each farm type.
- *Common Agrarian Policy (CAP) constraints*. It is assumed the CAP regulation regarding subsidised crop area requirements.
- *Rotational constraints*. Alfalfa is the sole non-annual herbaceous crop, remaining in the ground for four years, after which it cannot be sown again for three years (the salutary interval before repeating alfalfa in the same plot). Corn cultivation after rice and the corn cultivation frequency have also been limited.
- *Market constraints*. The area of some crops (ornamentals and orchards) is limited to the maximum area utilised in the period 1997-2000.
- *Type of soil constraints*. In the wetlands only rice can be cultivated. Also, there are zones near the rivers and with low quality soils where only poplars and winter cereals can be cultivated.

In all the restrictions it is considered that the surface available for the herbaceous cultures is the surface not occupied by ligneous cultures, which present a much more prolonged occupation of the ground. The detailed model can be studied in Pujol (2002).

The weights of the different objectives of the utility functions corresponding to each one of the productive orientations are found in Table 2.

Validation

Validation of the estimated utility functions was based on comparing the real decisions about production in the present situation with the model predictions when the irrigator maximises the model's utility function. The comparison of model predictions with real system outputs is, in practice, a common procedure to validate models (Qureshi *et al.*, 1999).

Specifically, the existing differences between the percentage distributions of cultures in the actual situation and the predictions of the model for each productive orientation have been compared.

The predicted and observed values of decisions on production are compared in Table 3. The only considerable deviations between the model and reality take place in 'mixed' productive orientations of corn and sunflowers in the Muga and the Middle Ter. Nevertheless, in general terms the model can be considered acceptable.

Obtaining the water demand curves

In order to obtain the water demand curves corresponding to each productive orientation, the point of departure is its utility function. In the calculation of the gross margin an additional cost must be included: the price of the water. Successive increases in the price of the water have been considered, supposing the application of volumetric tariffs, and starting from a price level of zero, equivalent to the present situation (in which the irrigators only pay a surface tariff, not in function of the volume of water consumed). Each price level is a scenario in which the utility function is maximised. The set of obtained water consumptions forms the demand function. This process was repeated for each productive orientation.

The demand curves obtained allow the consequences of possible tariff increases resulting from a more or less strict application of the WFD to be deduced and compared with the current situation.

Simulation of the water markets

The simulation of water markets was made using the methodology developed by Arriaza *et al.* (2002), who applied their model in south western Spain. Our case study applied the methodology to north eastern Spain in quite different socio-economic and agronomic contexts.

In order to simulate the market, the joint performance of the demands of the various existing productive orientations, as well as the existence of a limited supply of water, determined by the hydraulic authorities, was analysed. The simulation assumed perfect competition and the non-existence of transaction costs. The model is explained in detail and an example is developed in the results section.

The simulation was made at two levels: intra-community and inter-community. The first case supposed a market where only the farmers who belong to the same zone compete. Three intra-community water markets were simulated: the Muga, the Middle Ter and the Lower Ter.

In the second case an inter-community water market was simulated. It was assumed that the irrigators of a same river basin (the Ter) could transfer part of their supply to each other, with no need for new infrastructures. This would not be possible in the case of communities pertaining to different river basins,

Table 3. Deviations between real and simulated values of the percentage of cultivated surface

	Muga			Lower Ter				Middle Ter			
	Corn	Livestock	Mixed	Mixed	Fruit	Livestock	Corn	Corn	Mixed	Livestock	Ornamental
Corn	–3.21	3.24	–11.45	–3.53	–0.72	0.55	1.09	5.80	–13.00	–1.67	0.00
Sunflower	2.32	0.00	12.60	4.34	0.93	0.00	0.14	0.00	13.10	0.00	0.00
Grain cereal	0.00	1.61	0.00	0.00	–2.18	0.98	–0.09	0.00	–0.90	2.47	0.00
Winter forage	0.00	–1.37	0.00	0.00	1.85	–0.83	0.07	0.00	0.77	–2.10	0.00
Alfalfa	2.96	–1.87	0.00	0.00	0.00	0.29	0.00	0.00	0.00	3.76	0.00
Rice	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fruit trees	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ornamental trees	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poplars	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Set-aside	–2.07	–1.61	–1.15	–0.81	0.12	–0.98	–1.29	–5.61	–0.20	–2.23	0.00

since infrastructures that do not exist at present would be required to physically transfer the water. Therefore, a water market between the Lower Ter and the Middle Ter was simulated, and the average water demands of these two zones were analysed.

Results

Obtaining the water demand curves

The methodology described above was employed with the aim of improving predictions of farmers' behaviour, which in turn would provide better predictions for policy analysis. Applying the weights estimated for the surrogate utility function found in Table 2, normalised to different prices of water, generates a demand curve when the utility function is maximised for different water prices. The aggregated water demand curves have also been generated. In these cases, the demands of the individual farm types have been added, weighed according to the importance of their surface area.

Figure 2 shows an example of water demand curves for the Lower Ter irrigation community group. This figure shows the demand of the four productive orientations and also the average demand for the zone. The differences between the demands of the different irrigators, closely linked to the economic value of output, can be observed. In this sense, the behaviour of the demand curve of the fruit orientation is remarkable because it obtains a higher gross margin of its production than the other orientations. This difference in demand demonstrates the potential for a water market and implies that irrigators might potentially be interested in participating in it.

Simulation of the water markets

The simulation methodology can be explained taking the Lower Ter community group as an example. Fig. 2 illustrates the analysis. A water quota imposed by the hydraulic authorities of 4,000 m³ ha⁻¹ has been simulated. Point *E* defines aggregated demand (computed by multiplying each farm type demand by

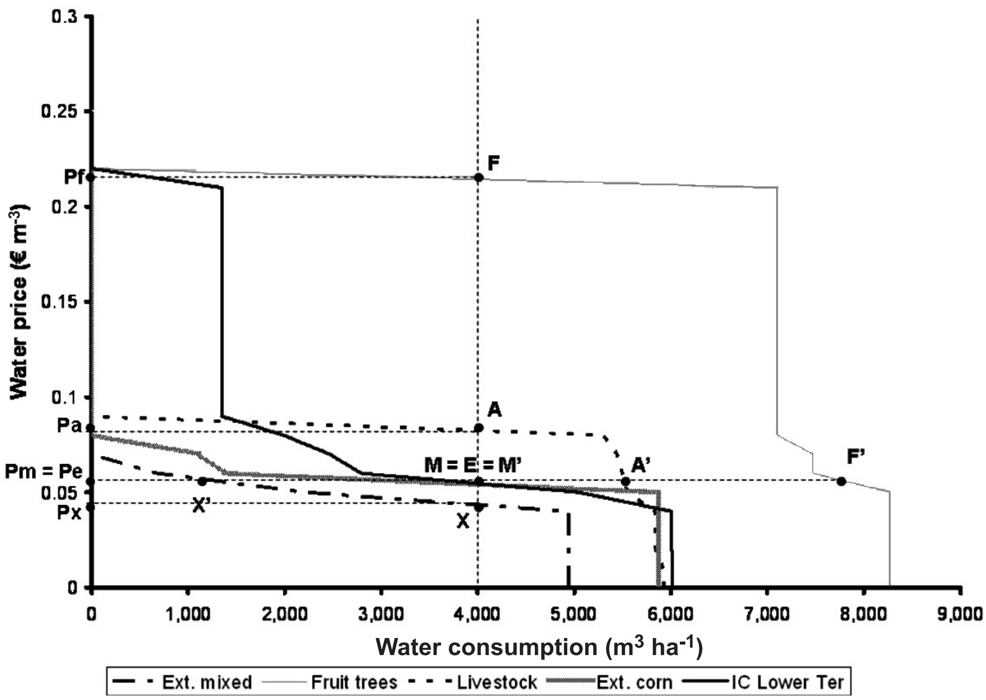

Figure 2. Water market in the Lower Ter for a quota of 4,000 m³ ha⁻¹.

its area) for this quota, and P_e is the corresponding equilibrium price. At this price, different farm types, *A'* ('livestock'), *X'* ('mixed'), *M'* ('corn'), *F'* ('fruit'), demand quantities of water which are different from the 4,000 m^3 ha^{-1} available.

Consequently, under conditions without transaction costs, if a market is created, quantities bought and sold by farmers will maintain the average global consumption (Q = 4,000 m^3 ha^{-1}) but will search for a new equilibrium since transactions will imply that the utility of water is higher for the 'fruit trees' and 'livestock' farm types and lower for 'mixed' ($Pf > Pe$ and $Pa > Pe$, and $Px < Pe$). Water will be sold by 'mixed' users, moving from *X* to *X'*, while 'livestock' moves from *A* to *A'* and 'fruit' moves from *F* to *F'*. 'Corn' is almost in equilibrium and there are no water transactions as *M* lies just above the aggregated average for Q = 4,000 m^3 ha^{-1} ($Pe \approx 0.05$ € m^{-3} and $Pm = Pe$).

As can be seen, for this quota the marginal utility measured in monetary terms corresponding to the aggregate demand is close to 0.05 € m^{-3}, which almost coincides with the marginal utility of the farm type 'corn' but is higher than that of 'mixed' and lower than that of 'livestock' and 'fruit'.

In this case, if a water market is opened up, with the assumptions of no transaction costs and perfect competition, the water use of the 'corn' farm type will remain unchanged while 'mixed' will sell water to 'fruit'and 'livestock'. Tables 4 and 5 summarise the results of the application of internal markets, limited to each community irrigation group, in different situations of water availability. The two tables present the situations corresponding to different equilibrium prices, and each price corresponds to an amount of water supply.

However, a market could also be established between the Middle and Lower Ter communities. In this case an interesting result is obtained because, as Table 6 shows, transfers move from the Middle to the Lower Ter when water is slightly limited while water goes in the opposite direction as water scarcity increases.

Discussion

Utility functions

As opposed to many other works, where the relevance of the multiplicity of objectives in irrigator decision-making has been demonstrated (Zekri and Romero, 1992; Sumpsi *et al.,* 1996; Amador *et al.,* 1998; Berbel and Rodríguez-Ocaña, 1998; Gómez-Limón and Berbel, 2000; Bazzani *et al*., 2002; and Gómez-Limón *et al.,* 2002), in this case study the high-priority objective is the maximisation of the gross margin. According to the results obtained, only some farm types consider the minimisation of manual labour and the minimisation of risk to be objectives. Therefore, in many cases, the use of a mono criterion model in the simulation could be justified.

Table 4. Internal markets limited to each irrigation community group. General data

		Transaction price (€ m^{-3})				
		0.01	**0.03**	**0.05**	**0.07**	**0.09**
Muga	Allocation (hm^3 per 100 ha)	0.54	0.53	0.52	0.26	0.18
	Total market transaction (hm^3)	0.89	0.78	0.84	3.91	0.49
	% traded water over quota	3.19	2.82	3.09	28.44	50.66
	Value of market (€ × 1000)	8.92	23.43	42.33	273.52	43.80
Lower Ter	Supply (hm^3 per 100 ha)	0.60	0.60	0.50	0.25	0.13
	Total market transaction (hm^3)	3.04	3.05	6.83	9.30	7.76
	% traded water over quota	7.11	7.16	19.06	53.12	81.00
	Value of market (€ × 1000)	30.41	91.64	341.68	650.78	698.20
Middle Ter	Supply (hm^3 per 100 ha)	0.54	0.53	0.50	0.45	0.26
	Total market transaction (hm^3)	2.01	2.08	2.21	2.42	2.97
	% traded water over quota	24.63	26.16	29.24	35.61	76.30
	Value of market (€ × 1000)	20.14	62.52	110.70	169.70	267.21

Table 5. Internal markets within each irrigation community group. Transactions by farm type (m^3 ha^{-1}) and by transaction price (€ m^{-3})

			Transaction price (€ m^{-3})				
			0.01	**0.03**	**0.05**	**0.07**	**0.09**
Farm types buying (m^3 ha^{-1})	Muga	Corn	701	745	811	–645	–172
		Livestock	96	2	–138	2,339	–184
		Mixed	–356	–312	–246	–1,291	194
	Lower Ter	Mixed	–1,076	–1,066	–2,831	–2,465	–1,349
		Fruit	2,254	2,264	3,226	5,010	5,751
		Livestock	–95	–169	503	2,980	–1,349
		Corn	–146	–136	826	–1,346	–1,349
	Middle Ter	Corn	205	346	609	–2,999	–2,412
		Mixed	–4,569	–4,638	–5,047	–4,539	–2,594
		Livestock	–46	–116	–32	221	–2,594
		Ornamental	5,749	5,890	6,153	6,661	8,606

Negative quantities refer to water sold and positive quantities to water bought.

Table 6. Inter-community water market transactions

Price (€ m^{-3})	0.01	0.03	0.05	0.07	0.09
Allocation (hm^3 $100ha^{-1}$)	0.59	0.59	0.50	0.28	0.16
Area buying (m^3 ha^{-1})					
Lower Ter	99	122	0	–362	–217
Middle Ter	–470	–578	–1	1,712	1,028
Total market transaction (hm^3)	0.70	0.87	0.00	2.57	1.54
% transaction over volume	1.38	1.71	0.00	10.56	11.45
Value of market (€ × 1000)	7.05	26.01	0.07	179.76	138.79

In the section «area buying», negative quantities refer to water sold and positive quantities to water bought.

Water demand curves

All the demand curves obtained present similar characteristics. At low price levels, the demand is relatively inelastic: starting from the present situation, small tariff increases would modify little or not at all (according to the farm type) the demand for water. Nevertheless, when the tariff increases, all the curves present a very elastic zone, from which new price increases would cause drastic changes in demand and, therefore, in decisions on production and the gross margins obtained. Finally, at very high tariff levels, the demand returns to being elastic (it is the zone in which the irrigator produces dry land cultures). These results coincide with those obtained in other studies such as those of Berbel and Gomez-Limón (2000), Gómez-Limón and Berbel (2000) and Arriaza *et al*. (2002).

Water markets

In the case of applying internal markets limited to each community irrigation group (Tables 4 and 5), the farmers might achieve higher levels of utility if a market was available, the reason being that each farmer buys/sells his water, improving his result until the increase in marginal utility from selling water is offset by the reductions in gross margins from crop production.

Tables 4, 5 and 6 show that water market transactions reach their maximum level when water availability is low (2,000 to 3,000 m^3 ha^{-1}). In all the cases, the existence of a market under conditions of water restriction improves the social welfare of farmers (measured as an aggregate utility function value) vis-à-vis a non-market situation.

In the case of intra-community markets, comparing the utility increases between the 'with market' situation and the 'without market' situation for different supply levels leads to the following observations.

In the Muga the maximum utility increases in the 'corn' orientation occur for low levels of restriction (supply higher than 5,350 m^3 ha^{-1}), in which case the increase of the utility surpasses 4%. In 'livestock', the effect is superior to very inferior allocations: around 2,700 m^3 ha^{-1} results in increases of more than 20%. And in the 'mixed' orientation, 2,050 m^3 ha^{-1} increases the utility by more than 3%.

In the Lower Ter, most remarkable is the elevated utility increase of the 'fruit' orientation. For the interval of supply between 6,000 and 1,350 m^3 ha^{-1}, the utilities vary from 13% to 124%. The 'livestock' orientation shows interesting effects for supplies lower than 2,800 m^3 ha^{-1}, the point at which the utility increase reaches 27%. On the other hand, the effect of the market is very small in the 'mixed' and 'corn' orientations. In this last case, for levels between 2,000 m^3 ha^{-1} and 1,350 m^3 ha^{-1}, the utility increases from 6-10%.

In the Middle Ter the case of the 'ornamental' productive orientation can be emphasised. For a very wide range of supply (from 5,450 to 2,600 m^3 ha^{-1}), the utility increase is very high, varying between 70% and 110%. The 'mixed' orientation also obtains high increases in its utility function. The 'corn' orientation obtains increases of 5% for allocations of 5,050 m^3 ha^{-1}. Finally, the 'livestock' orientation only obtains elevated increases of utility at low levels of allocation: 2,600 m^3 ha^{-1} corresponds to an increase of 12%.

The existence of a water market, in situations of limited water availability, improves the irrigator's utility and his economic gain, but generally the increase in gain is quite moderate. For example, in the zone of the Muga, in a situation of high restrictions (supply of 18,400 m^3 ha^{-1}) (Table 7), the existence of the intra-community market would increase the gross margin of the zone by 36,800 € (7.05 € ha^{-1}). In addition, the gain improvement does not compensate the reduction caused by the low amount of water available, with respect to a year without restrictions.

In the present situation, in cases of drought, the hydraulic authority reduces the allocations to the irrigators, granting different water quantities according to production (fruit trees or other cultures), and this produces conflicts between the different farm types. The existence of water markets, associated with a change of policy, granting equal allocations by hectare for all irrigators, could facilitate a reassignment of the resource among them, reducing these conflicts. In contrast to allocation by administrative decision, allocation by means of a market can provide remuneration for farmers who stop using the water in drought situations.

Table 7. Comparison between the situations «with market» and «without market» in the Muga zone (supply of 18,400 m^3 100ha^{-1})

	Without market	**With market**
Corn		
Gross margin (€ 100ha^{-1})	31,954.42	32,259.20
Labour (h ha^{-1})	663	610
MOTAD (risk estimator)	2,562,203	2,507,504
Livestock		
Gross margin (€ 100ha^{-1})	19,980.50	20,395.54
Labour (h ha^{-1})	959	894
MOTAD (risk estimator)	853,547	819,541
Mixed		
Gross margin (€ 100ha^{-1})	35,750.38	36,815.78
Labour (h ha^{-1})	1,830	3,442
MOTAD (risk estimator)	3,184,840	3,601,416

From a modelling point of view, the market seems to be a feasible solution used at the intra-sectoral level to solve problems of resource allocation in the case of drought. Nevertheless, an important element to consider is the effect of transaction costs that could limit the transactions because they could considerably diminish the benefit for the participants.

Analyses of the viability of the introduction of intercommunitarian water markets in the Guadalquivir and in the Duero were carried out by Garrido (2000) and Martínez and Gómez-Limón (2004), respectively. In both cases the authors conclude that water markets improve the allocation of the resource from an economic point of view, although the transaction costs can limit their practical application. In both studies the obtained results originate a more important economic impact and water reassignment than that obtained in the internal river basins of Catalonia.

Also, these authors suggest other reasons that can limit the effectiveness of the market. The present legislation does not develop in enough depth all of the aspects related to the water market, and this can cause insecurity. Also, the traditional belief that water is common property and that it is not possible to buy or sell it is firmly implanted in the irrigators' minds.

Opinions of the irrigators

It is also important to know whether a water market would be accepted in practice by the irrigators. As Bjornlund (2003, p.58) indicates, «for water markets to realise the above benefits, irrigation communities must adopt the concept of markets, see their benefits and possibilities and learn how to utilise them to their fullest potential». The results of the interviews conducted indicate that the communities of the Muga are the most reticent about the establishment of markets (one of them established a formal prohibition of the purchase, sale or transfer of water in their Statutes.) The communities of the Lower Ter show an intermediate position, identifying the need for Administration control of the transactions. In the Middle Ter, the transactions would be accepted if economic compensation was provided for the irrigators. These results seem to show that water markets would be accepted differently from zone to zone.

However, Garrido *et al.* (1996) point out the disadvantages for the people in question when faced with a new situation that is in conflict with one which has always been familiar. It is therefore necessary to be careful when interpreting the irrigators' opinions.

In fact, in studies carried out in other zones of the world where the introduction of water markets is recent, it has been observed that when the irrigators obtain advantages from market participation, the use of markets increases considerably in the initial years of operation (Bjornlund, 2003). It is expected that a water market in the zone of study, operating correctly, would have a similar effect.

As conclusions, the water markets applied to the internal river basins of Catalonia would guarantee an optimal reassignment of the resource in situations of supply restrictions. Although in the analysed zone they would not imply very high economic gains with respect to the situation without a market, they would avoid conflicts between irrigators. The markets would favour the internal water management organization of the agrarian sector, transcending the problems caused by the performance of the Administration, which grants different amounts of water to the irrigators according to what they cultivate.

In addition, the introduction of the markets would allow water management policy to be updated in accordance with the Spanish legislation and in line with the WFD that does not mention water markets explicitly but promotes the use of economic tools in water management. The main elements of doubt are the irrigators' practical acceptance of this new tool and the transaction costs, related to the operative complexity of the market.

The next logical step would be to analyse the possibility of establishing an intersectoral market between the irrigators and the municipalities in order to guarantee the urban supply in case of drought.

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