MULTICRITERIA ANALYSIS OF IRRIGATION WATER MARKETS: A SPANISH CASE STUDY*

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Abstract

This paper develops a multi-criteria methodology to simulate irrigation water markets at basin level. For this purpose it is assumed that irrigators try to optimise personal multi-attribute utility functions with their productive decision making (crop mix), subjected to a set of constraints based upon the structural features of their farms. In this sense, farmers with homogeneous behaviour about water use have been grouped, being this groups established as agents "type" to be considered in the whole model for water market simulation. This model for market simulation calculates the equilibrium through a solution that maximises the aggregate welfare, quantified as the sum of the multi-attribute utilities reached by each one of the participating agents. This methodology has been empirically applied for the Duero basin (Northern Spain), obtaining as main result that the implementation of this institution increases economic efficiency and agricultural labour demand, particularly during shortage periods (droughts).

Keywords: *Multi-Attribute Utility Theory, Irrigation water, Duero Valley (Spain).*

1 INTRODUCTION

The constantly rising demand for water in Spain clearly demonstrates the growing relative shortage of this resource. In fact, most of Spanish basins have already a situation known as a "mature economy of the water" (Randall, 1981). This has motivated an intensive polemic about the efficiency of use of this natural good by irrigated farms, which utilise 80 per cent of the national water consumption (Ministry of the Environment, 2000). The apparently poor management of water in Spanish irrigated areas (large losses of water and its application to surplus crops, with low profitability and low labour demand) has served as an argument for the implementation of demand water policies as an indispensable solution to this problem. In this way the Spanish authorities have recently introduced a new legislative framework that includes higher water pricing, complying with the European Water Framework Directive, a new subsidy scheme in order to achieve water conservation in irrigated areas, and the introduction of water markets. This paper is only focused in this economic instrument.

The introduction of water markets has been traditionally thought as a measure to improve, in a decentralised manner, the allocation of water resources among its potential users and to reduce the effects of the water scarcity. Thus, the kindness that justify the introduction of water markets have been based in its availability to reallocate water among the different uses toward those with more value, promoting at the same time a more rational employ of the resource in every use. In this way, as many authors agree (Spulber and Sabbaghi, 1994; Easter and Hearne, 1995;

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Thobani, 1997; Lee and Jouravlev, 1998 and Howe and Goemans, 2001), this economic instrument allows palliating the inefficiencies that public management (allocation) of water till now developed has demonstrated. According to the literature, with market institutions it is possible to reach water allocation efficiency better than with anyone of its alternatives, maximizing society welfare (Vaux and Howitt, 1984; Howe *et al.*, 1986; Rosengrant and Binswanger, 1994; Easter and Hearne, 1995).

Although the introduction of water markets allows different institutional arrangements (Lee and Jouralev, 1998), this paper is focused exclusively in the water market that has been introduced recently in Spain by the Water Act (Act n. 46/1999), whose development appears in article 61 *bis*. In short, among the different alternative systems of water use rights transfers, the Spanish legislation has opted to limit these transactions to the leasing ones (sale and purchase of water and not of rights), water markets known as *spot* markets.

In this sense, the objective of this research is the simulation of a spot market of irrigation water for a whole basin, in order to analyse the economic impact (increase of economic efficiency through profits measurement) and social impact (change in demand of labour by the agricultural sector) that the effective application of this economic instrument would generate.

2 METHODOLOGY

The literature has a number of empiric studies about modelling economic, social and environmental impacts of water markets (e.g. Houston and Whittlesey, 1986; Dinar and Letey, 1991; Weinberg *et al.*, 1993; Horbulyk and Him, 1998; Garrido, 2000, or Arriaza *et al.*, 2002). In general, these authors conclude that the implementation of water markets increase this resource allocation efficiency.

Although our work has been influenced by the studies mentioned above, its major contribution is methodological, developing as a novelty a simulation model base upon MCDM techniques. In fact, we have assumed as starting point that, unlike the classical approach, the level of farmers' utility is determined not only by the profit but also by other relevant management criteria considered by them. Thus, this study supposes the amount of water that producers consume or sell depends on the *multi-attribute utility* generated by this resource for this decision makers, considering the relative importance that these farmers assign to each one of the different criteria that are tried to be simultaneously optimised (Gómez-Limón *et al.*, 2003).

2.1 Multi-Attribute Utility Theory (MAUT) approach

One of the basic principles of classical economic theory is that decision-makers behave as profit maximisers. Following this principle, the problem of agricultural producers could be adequately modelled by the maximization of single-objective models. Real-life observations refute this simplification. Many authors have shown the complexity of the farmers' decision making process through empiric studies, demonstrating they consider more than one attribute in their utility functions: e.g. Berbel and Rodríguez (1998), Costa and Rehman (1999), Willock *et al.* (1999) or Solano *et al.* (2001). All these studies suggest that farmers' decision-making processes are driven by various criteria, usually conflicting ones, related with their economic, social, cultural and natural environment conditions in addition to the expected profit, such as the maximization of leisure, the minimization of managerial problems, the minimization of indebtedness, etc.

In this framework a decision maker takes his decisions trying to satisfy, insofar as possible, all these criteria at the same time. Considering, therefore, the existence of multiple objectives in farmers' decision making, it seems appropriate to focus the simulation of water markets inside the Multi-Criteria Decision Making (MCDM) paradigm.

Recognising the convenience of including several objectives to simulate the producer's behaviour, we resort to Multi-attribute Utility Theory (MAUT), an approach largely developed by Keeney and Raiffa (1976), to overcome the limitations of the single-attribute utility function. The aim of MAUT is to reduce a decision problem with multiple criteria to a cardinal function that ranks alternatives according to a single criterion. Thus, the utilities of n attributes from different alternatives are captured in a quantitative way via an utility function, mathematically, $U = U\ (r_1,\ r_2\ ...\ r_n)$, where U is the Multi-Attribute Utility Function (MAUF) and r_j are the attributes regarded by the decision-maker as relevant in the decision-making process.

Usually, additive and linear utility functions have often been adopted for simulating farmers' behaviour in a multi-attribute framework. 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. Mathematically the related utility function would be:

$$U_i = \sum_{j=1}^{n} w_j k_j r_{ij}\ , \qquad i = 1, ..., m \qquad [1]$$

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

2.2 Agents "type" operating in the market

Given the practical impossibility of simulating a water market at hydrographical basin level considering all individual irrigators as operating agents, it is necessary to aggregate these producers in homogeneous groups that include irrigators with similar behaviour related to water use. This paper dispatches from the basic idea that farmers' behaviour (i.e. water use) is motivated by their productive potentialities (derived from the structural conditions of their farms) and by the relative importance that these producers give to the different management criteria, condensed in their respective MAUFs (Gómez-Limón *et al.*, 2003). Thus, the homogeneous groups that have been established in order to constitute the agents "type" in water market modelling are the result of a double entrance typology, in which operating agents (irrigators) are sorted considering the structural conditions of their respective holdings and the different weights given to the objectives considered as classificatory variables.

This way, it can be assumed that each one of these clusters obtained, as results of this binomial typology "productive potentiality" (irrigated area) / "shape of farmers' MAUF" (cluster), have the enough internal homogeneity to consider the respective average virtual farmers as representative cases of the different agent "type" operating in the water market, in order to be separately modelled without unwished bias.

In this sense, it is also important to note that the homogeneous groups obtained in this way can be regarded as 'fixed' in the short and medium terms. This means that the selection variables chosen allows farmers to be grouped into clusters irrespective of any change in the policy framework (i.e. water market). In other words, once the homogeneous groups of producers have been defined, we can assume that all elements inside each group will behave in a particular way when the policy variables change; that is, crop-mix decisions will be modified in a similar fashion by all farmers within a cluster, although such modifications would differ among the individual groups defined.

2.3 Elicitation of the Multi-attribute Utility Functions

Once we agree to use additive and linear utility functions, the ability to simulate real decision-makers' preferences is based on the estimation of relative weightings. Sumpsi *et al*. (1997) and Amador *et al*. (1998) propose a method for assessing a farmer's additive and linear MAUFs (weights vector) without direct interaction between farmers and the researcher. They show how it is possible to elicit the farmer s' utility function by observing only the actual crop distribution upon weighted goal programming. We adopt this methodology to assess the utility function of a group of farmers as previously has been done by Berbel and Rodríguez (1998), Gómez-Limón and Berbel (2000), Arriaza *et al*. (2002) and Gómez-Limón *et al*. (2002).

In our case study the following objectives are selected 'a in order to explain farmers' behaviour has been: the maximization of Total Gross Margin (TGM), the minimization of risk, measured as the variance of the TGM (VAR), and the minimization of the Total Labour input (TL).

Following this technique to elicit weights (w_j) devoted to each management criteria, the additive and linear utility function obtained in each case has the following structure:

$$U = \sum_{j=1}^{n} w_j k_j f_j(\vec{X}) \qquad [2]$$

where k_j is a normalising factor and $f_j(X)$ is the mathematical expression of attribute j.

The proposed method provides subrogated utility functions that can be used as an instrument capable of reproducing the observed behaviour of farmers. In this way it is worth mentioning that this technique was used several times, once for every homogeneous group of producers or "agent type" defined in order to obtain the characteristic MAUF of each of them. Thus, these MAUFs are considered to be the ones that the set of farmers included in each one of these groups try to maximise every time, despite the different possible scenarios to be faced (e.g. different effective endowments of water). This is the key issue that allows the simulation of a hypothetical water market framework.

2.4 Modelling irrigation water market at basin level

Taking into account the comments above it can be suggested that the problem of decision making that faces every individual irrigator in the short term (i.e. annual crop mix decision) can be simulated through a mathematical programming model whose objective function is the MAUF built upon the weights vector (w_j) calculated in each case, subject to the different technical and institutional constraints that need to be fulfilled. Therefore, beginning with the case where water exchanges are not possible (lack of water market), the problem proposed would be outlined as follows:

$$\text{Max} \quad U(\overrightarrow{X}) = w_{TGM} K_{TGM} TGM(\overrightarrow{X}) - w_{VAR} K_{VAR} VAR(\overrightarrow{X}) - w_{TL} K_{TL} TL(\overrightarrow{X}) \quad [3]$$

$$\text{s.t.:} \quad \sum_c X_c \leq S \quad [3.a]$$

$$\sum_c WD_c X_c \leq D \cdot S \quad 3.b]$$

$$\overrightarrow{AX} \leq \overrightarrow{B} \quad [3.c]$$

$$X_c \geq 0 \qquad \forall c \quad [3.d]$$

where w_{TGM}, w_{VAR} and w_{TL} are the weights estimated for the different objectives considered by the producer, k_{TGM}, k_{VAR} and k_{TL} are the normalising factors, X_c is the surface dedicated to crop c (in ha), S is the total surface available for cropping activities (in ha), WD_c are the water demands for crop c (in m^3/ha) and D is the total endowment of water available (in m^3/ha).

Thus, in this basic model the constraints linked with land [3.a] and water [3.b] availability are explicitly pointed out. The generic set of constraints [3.c] is related with the rest of constraints (CAP limitations -set-aside requirements and sugar-beet quotas-, crops frequency and rotational needs and market limitations).

If this individual producer would be allowed to exchange water through a spot market, the optimisation model exposed became in this one:

$$\text{Max} \quad U(\overrightarrow{X}) = \qquad [4]$$

$$= w_{TGM} K_{TGM} \left\{ TGM(\overrightarrow{X}) + \sum_j \left[\left(P_m - \frac{TC_{ij}}{2} \right) S_{ij} \right] - \sum_j \left[\left(P_m + \frac{TC_{ji}}{2} \right) P_{ij} \right] \right\} -$$

$$- w_{VAR} K_{VAR} VAR(\overrightarrow{X}) - w_{TL} K_{TL} TL(\overrightarrow{X})$$

$$\text{s.t.:} \quad \sum_c X_c \leq S \qquad [4.a]$$

$$\sum_c NH_c X_c - \sum_j V_{ij} + \sum_j C_{ij} \leq D \cdot S \qquad [4.b]$$

$$A\overrightarrow{X} \leq \overrightarrow{B} \qquad [4.c]$$

$$X_c \geq 0 \ ; \ P_m \geq 0 \qquad \forall c \qquad [4.d]$$

where P_m is the market price of water (in €/m^3), TC_{ij} are the transaction costs that involve a transfer of water from the irrigator considered (i) to other irrigators (j), measured equally in €/m^3, S_{ij} are the water quantities sold from i to j (in m^3) and P_{ij} are the amount of water purchased from i to j (in m^3).

In this sense it is convenient to point out that the transaction costs are parameters proposed upon the starting point and the end of each transfer. For this reason, TC_{ij} does not have to be equal to CC_{ji}. Thus, for our model definition these TCs take different values. It has been considered a minimum value (equal to 0,005 €/m^3) when the water transactions are done inside an irrigated area. When these transfers are carried out among different irrigated areas using natural flows (down stream) as transport paths, the TCs take a value of 0,01 €/m^3. Finally, for the rest of cases, where no transport infrastructure exists (any transfer is physically infeasible), a maximum value tending to infinite has been considered (in an operative way 10 €/m^3 has been taken). For every case, it has been supposed that sellers and purchasers in similar halves share these transaction costs.

Widening the approach followed for the optimisation problem of an individual irrigator or agent "type" i, the market equilibrium reach by interaction of all of then can be simulated through the following mathematical problem:

$$\text{Max} \quad \sum_i K_i U_i \left(\overrightarrow{X_i} \right) = \qquad [5]$$

$$= \sum_i K_i \left\{ \begin{array}{l} w_{TGM_i} K_{TGM_i} \left\{ TGM_i(\overrightarrow{X_i}) + \frac{1}{K_i} \sum_j \left[\left(P_m - \frac{TC_{ij}}{2} \right) S_{ij} \right] - \frac{1}{K_i} \sum_j \left[\left(P_m + \frac{TC_{ji}}{2} \right) P_{ij} \right] \right\} - \\ - w_{VAR\,i} K_{VAR_i} VAR_i(\overrightarrow{X_i}) - w_{TL\,i} K_{TL_i} TL_i(\overrightarrow{X_i}) \end{array} \right\}$$

$$\text{s.t.:} \quad \sum_c X_{ci} \leq S_i \qquad \forall i \qquad [5.a]$$

$$\sum_i \sum_c K_i WD_c X_{ci} \leq \sum_i K_i D_i S_i \qquad [5.b]$$

$$\sum_c WD_c X_{ci} - \frac{1}{K_i} \sum_j S_{ij} + \frac{1}{K_i} \sum_j P_{ij} \leq D_i S_i \qquad \forall i \qquad [5.c]$$

$$Uo_i \leq U_i \qquad \forall i \qquad [5.d]$$

$$A_i \cdot \overrightarrow{X_i} \leq \overrightarrow{B}_i \qquad \forall i \qquad [5.e]$$

$$X_{ci} \geq 0 \ ; \ P_m \geq 0 \qquad \forall c \ \forall i \qquad [5.f]$$

where K_i are the normalising factors used to modulate each agent's "type" representativeness. Indeed, to allow a sum of the utilities (U_i) reached by each one of them in a homogeneous way, these factors have been equalled, for each case *i*, to the ratio total surface represented by the agent "type" divided by the respective average surface (ST_i/S_i). Therefore, the sum proposed as objective function adds properly the utility generated by each irrigated hectare for the corresponding producers.

With this model it is assumed that the market equilibrium is reached when the sum, properly weighted, of the utilities U_i of all agents considered is maximized. Nevertheless, it is convenient to comment that in order to simulate the market in an appropriate way it has been compulsory to include two new constraints with regard to the model [4]. The first one, noted as [5.b], it related with the whole water balance, assuring that the water consumed at basin level is smaller or equal to the total available resources.

In [5.d] a set of constraints are also included in order to guarantee that the market operates without anybody "loses". In fact, when being the water exchanges voluntary, the different agents only would participate in the market just in case the transfers could increase their welfare (an increase of their utility function). For this reason it is necessary that the utility reached by each agent (U_i) in the equilibrium were superior, or at least equal, to the utility that each one of them achieved before the reallocation done by the market has been reached (Uo_i), this is, in the case were no market exists.

3 CASE STUDY

The Duero valley is a basin shared between Spain and Portugal. Nevertheless, the case study analysed here considers only the Spanish part that occupies most of the basin with almost 78,000 km^2. Inside this area studied there are 555,582 hectares devoted to irrigated agriculture consuming about 3,500 hm^3 of water annually as an average (about 6,300 m^3/ha·year). In fact, irrigation is the most important use of water in this basin, using 93% of total available resources. Rest of the water is used for urban purposes (6% of total resources availability) and industrial ones (1%). This preponderance of irrigation allows thinking that the biggest opportunities to improve the efficiency in resource uses at basin level through the market are based in the transfers that would be achieved among irrigators (transfers inside agricultural sector). Thus, simulating exclusively the irrigation water market it could be possible to analyse the lion's share of the socio-economic impacts that this institution would imply for the whole basin.

Irrigation in the Duero valley, as legally is established by the Spanish law, is divided in irrigated areas, internally managed by Water User Associations known as "*Comunidades de Regantes*" (CR). For this research, given the practical impossibility of considering all them, 7 representative CRs at basin level have been chosen, covering 51,343 irrigated hectares (9.2% of the total irrigation in the Duero).

In each of the irrigated areas considered it has been surveyed 367 farmers (an average of 52 producers for irrigated area) in order to gather the information needed to develop the cluster technique to generate homogenous groups (agents "type" definition), and later on to feed the models (technical coefficients for the objective functions and constraints). Thus for the construction of each agent's "type" models for weights estimation and for the final market simulation model, the technical coefficients were acquired as an average of the results obtained from the questionnaires belonging to the farmers included in each cluster.

Once the cluster technique have been applied in each CR, a total of 22 different homogeneous groups have been defined, constituting the agents "type" to be modelled. In Table 1 the basic features of each one of them can be observed.

Table 1. Agents' "type" main features

Irrigated area	Cod.	Name	% / n. farmers	% / sup. total	Main crops	Weights		
						w_{TGM}	w_{VAR}	w_{TL}
CR Canales Bajo Carrión	**11**	Part-time farmers	22,9%	17,8%	Maize, winter ce-reals and sugar-beet	0,724	0,276	0,000
	12	Livestock Farmers	21,3%	24,2%	Maize, alfalfa and winter cereals	0,465	0,535	0,000
	13	Small commercial farmers	27,8%	8,9%	Maize, alfalfa and winter cereals	1,000	0,000	0,000
	14	Risk averse farmers	27,8%	49,2%	Winter cereals and maize	0,671	0,329	0,000
CR Canal Margen Izda. del Porma	**21**	Large commercial farmers	40,7%	45,8%	Maize	1,000	0,000	0,000
	22	Part-time farmers	5,6%	5,4%	Winter cereals and maize	0,302	0,698	0,000
	23	Risk averse farmers	16,7%	16,6%	Winter cereals, Mai-ze and sunflowers	0,479	0,521	0,000
	24	Livestock farmers	37,0%	32,1%	Maize and alfalfa	0,852	0,148	0,000
CR Canal del Páramo	**31**	Risk neutral farmers	72,0%	69,6%	Maize, sugar-beet and beans	1,000	0,000	0,000
	32	Risk diversification farmers	28,0%	30,4%	Maize, winter ce-reals and sugar-beet	0,785	0,215	0,000
CR Canal del Pisuerga	**41**	Conservative farmers	20,6%	12,5%	Winter cereals and alfalfa	0,000	1,000	0,000
	42	Large commercial farmers	35,3%	57,5%	Winter cereals, su-gar-beet and maize	0,425	0,575	0,000
	43	Livestock farmers	44,1%	38,2%	Alfalfa, winter cereals, sugar-beet and maize	0,623	0,377	0,000
CR Canal de San José	**51**	Risk diversification farmers	35,3%	39,6%	Maize, winter cereals and alfalfa	0,544	0,456	0,000
	52	Young commercial farmers	35,3%	40,3%	Maize and sugar-beet	0,955	0,045	0,000
	53	Maize growers	29,4%	20,1%	Maize	1,000	0,000	0,000
CR Presa de la Vega de Abajo	**61**	Small elderly farmers	20,6%	11,5%	Maize and winter cereals	0,967	0,033	0,000
	62	Sugar-beet growers	29,4%	31,4%	Maize and sugar-beet	1,000	0,000	0,000
	63	Young commercial farmers	50,0%	57,1%	Maize, sugar-beet and winter cereals	1,000	0,000	0,000
CR Virgen del Aviso	**71**	Commercial farmers	45,5%	23,2%	Maize, sugar-beet and winter cereals	1,000	0,000	0,000
	72	Risk diversification farmers	24,2%	33,4%	Maize, winter ce-reals and sugar-beet	0,448	0,552	0,000
	73	Conservative farmers	30,3%	43,4%	Winter cereals, sun-flowers and maize	0,197	0,803	0,000

For each cluster obtained the multicriteria methodology already described has been applied for the calculation of the different weights vectors. The results obtained can be also observed in Table 1. About these results it is worth noting that there are important differences among the relative weights considered by the different groups, demonstrating the existence of large disparities in the MAUFs shape that each one try to optimise (i.e. difference in behaviour).

4 WATER MARKET SIMULATION RESULTS

4.1. Influence of water availability at basin level

Although the Duero valley does not display great oscillations in water availability, it is necessary to indicate that water scarcity problems can occur one out of 7-8 years. This circumstance makes interesting examine the effects that the reduction in water availability has on the amount of water transferred inside the scenario "with market". For this purpose the constraints [5.b] and [5.c] of the equilibrium model have been modified being substituted by the following expressions:

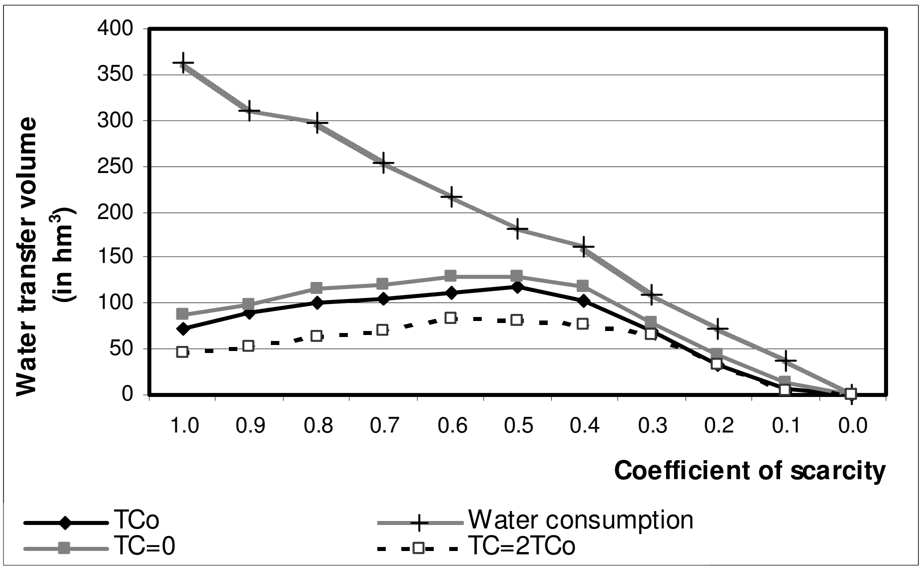
$$\sum_i \sum_c K_i WD_c X_{ci} \leq \sum_i K_i \lambda D_i S_i \qquad [5.b.bis]$$

$$\sum_c WD_c X_{ci} - \frac{1}{K_i} \sum_j S_{ij} + \frac{1}{K_i} \sum_j P_{ij} \leq \lambda D_i S_i \qquad [5.c.bis]$$

where the initial allotments (D_i) are multiplied by a coefficient of scarcity λ that takes values between 0 and 1, in such a way that the resources which agents "type" could hypothetically dispose are modified. For instance, when λ takes the value 1, the amount of water is equivalent to the theoretical allotment, whereas if coefficient λ takes the value 0, the water availability is null. Thus, parameterising λ different equilibrium solutions are reached, allowing to obtain curves that reflect the path of the main variables when the water irrigation availability is progressively reduced.

Figure 1 shows the variation of water transfers volume (line "TC_0") and the total resource consumption (line "water consumption") evolution when λ varies. In the absence of water scarcity (λ=1), the aggregated consumption of water reach 362 hm^3, being 71 hm^3 of those resources (19%) exchanged in the market. When water availabilities are reduced (λ diminishes), it can be observed that water transfers in the market take a rising path until reaching a peak that corresponds with a value of λ equal to 0.5. In this situation the total volume of water transferred is 117 hm^3, that supposes the 64 percent of the water consumed for this particular situation (181 hm^3). From that point, and as a result of the increasing water scarcity (λ values lower than 0.5), water flows in the market are reduced in absolute terms until zero.

Figure 1. Impact of water availability on transfers



A more detailed analysis of these results requires several additional comments. First, it is necessary to point that the evolution of transfers reflects the aggregated effect of increasing scarcity on the individual decision making (crop mix). In fact, farmers must modify their cropping patterns due to water shortages by reducing the surface devoted to those crops with greater water requirements (those of greater profits), or must purchase additional water into the market. In both cases the final result is a reduction in farmers' utility, because both possibilities suppose a decrease of farmers' TGM.

In this sense, due to farmers' utility maximisation behaviour, market allows reallocation of water towards uses that generates greater utility. Since the utility that this input generates is determined by both "objective" (soil productivity and another structural features of farms) and "subjective" (TGM weight) aspects, water transfer are produced towards greater productive irrigation areas and farmers with a higher commercial profile, that is, those that obtain greater increases of utility by the increase of profit (producers with greater values of w_{TGM}).

It is also interesting to emphasise another element that determines the direction of water flows: the geographic localization of farms. As an adequate infrastructures for the water transport does not exist in this basin, the only real possibility to achieve transfers is by using natural stream flows. For this reason irrigation areas located downstream (in our case the Canal de San Jose or Virgen del Aviso districts) have a certain comparative advantage, because of the possibility to buy water to all districts. This circumstance is not shared by other irrigated areas, which farms are located upstream and have less possibilities of buying water (smaller supply available).

As it has already commented, if we consider that farmers maximise their respective utility functions, market reach equilibrium situations when the marginal utility of water for all users are equalled to market price. Figure 2 shows the evolution of this water market price for different values of the coefficient λ.

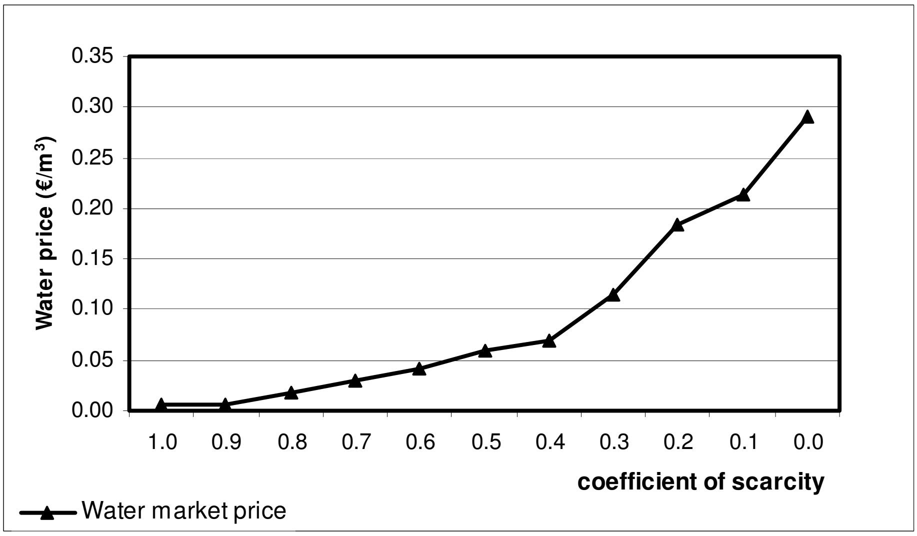


Figure 2. Water market price

As it is expected, the increasing scarcity of the water determines that marginal utility increases for all users and as a result market price rises. Water price increases from 0.005 €/m^3 for the normal hydrological situation (λ = 1), till 0,29 € for the last cubic meter of available resource in the basin for agricultural uses (λ =0).

Another aspect to be pointed out is the result obtained for the normal water supply situation (λ =1), that indicates that water transfers could reach the 19 percent of the total resources consumed. Nevertheless, it can be confirmed this does not happen in the reality, where no transfers are done. The causes of this market paralysis in the Duero basin, as in the other Spanish ones, are numerous. The most important one nowadays is the lack of a complete normative development, that properly defines the practical rules that must govern water markets. In particular, it exists a long delay in the definition of "consumption quotas" (water traditionally consumed) for the different irrigation areas, that determines the maximum amount of water that rights holders can lease, despite the amount of water rights legally registered. Without these values being published the administrative institutions of the basin cannot accede to approve agricultural origin transfers. Other causes that could make market operations difficult are the legal insecurity that the water sales produce and the consideration by farmers of water as a common property good (non-negotiable).

Figure 3 shows the aggregated gross margin (sum of total gross margin of all the agents properly weighted) evolution when coefficient of scarcity is parameterised. This aggregated variable can be used as an indicator of the total economic efficiency. Thus, it can be clearly observed that efficiency originated by the introduction of a water market (line "TC_o") is greater than the one generated by the scenario "without market" (line "without market"). It can be verified that under absence of water shortage conditions, aggregated gross margin "with market" reaches 60 million euros, a 18 percent more than the simulation with the scenario "without market", where only 49 million euros are obtained. This improvement of the economic efficiency also occurs for all possible values of λ (shortage situations), with an increase of the aggregated margin ranging from 12 to 20 percent.

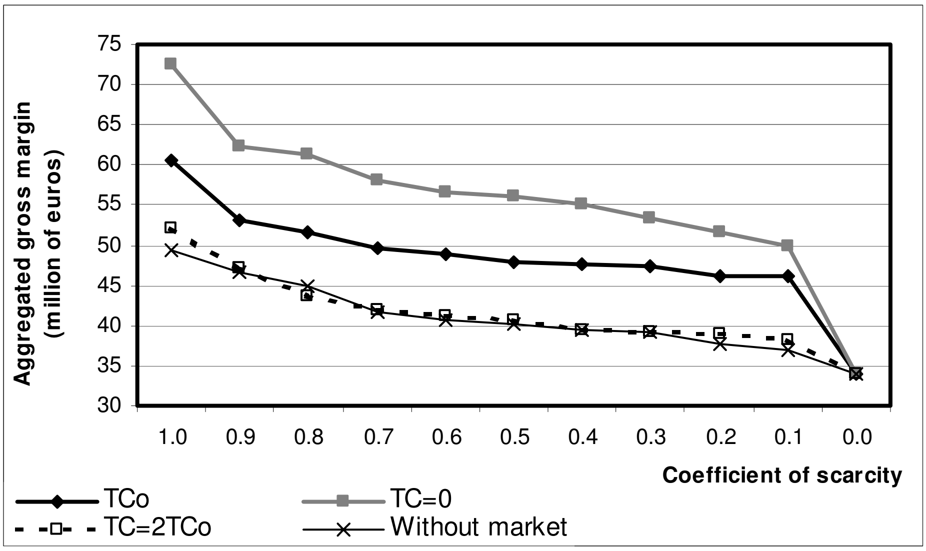
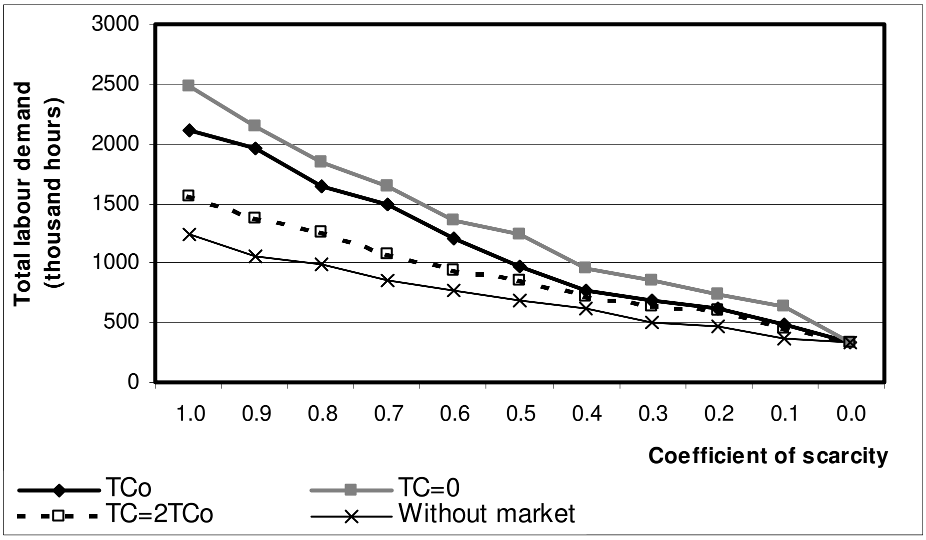


Figure 3. Impact of water market on aggregated gross margin (economic efficiency)

The reason for these significant gains in global efficiency is that water market allow different aggregated crop mixes (aggregated agents' production decision making) compared with scenario "without market". In fact, for every value of λ, the scenario "with market" devotes a greater surface to the more profitable crops, which have greater water and labour demands (vegetables, sugar-beet or maize), contrasting with the more extensive irrigation crops (winter cereals), less profitable and with smaller needs of water and labour inputs. Consequently, although the irrigation surface devoted to rain-fed crops (the least profitable ones) is increased to make possible achieve the global water balance, the final result is clearly positive, and the aggregated profit at basin level rises.

Due to the existence of a positive correlation between gross margin and labour, the increase in the economic regional efficiency caused by the introduction of water markets also promotes an increase in the agricultural employment generation. Figure 4 shows the effects on labour demand for the two scenarios already commented when coefficient λ is parameterised. First, it can be observed a decreasing aggregated labour demand as water availability drops for both scenarios. Secondly, it can be seen how scenario "with market" has higher demands of agricultural labour compared with the scenario "without market", with increases ranging from 20 to 45 percent. Therefore, this water demand policy instrument is adequate from a social perspective, since it can improve the present under-employment and high seasonability situations, favouring the fixation of population to the rural territory.

Figure 4. Impact of water market on total labour use (social impact)



4.1 Influence of the transaction costs

A second group of simulations have been done considering different levels of transaction costs. In this way results achieved with initial costs (already introduced in section 2.4; $TC=TC_0$) are compared with those obtained for a situation with no transaction costs (TC=0) and with another situation where these costs are duplicated ($TC=2TC_0$). These simulations allow to determine the key influence that the level of transaction costs has on the volume of transfers achieved by the market.

Figure 1 shows the changes in water transfers volume as a result of parameterisation of λ and for the different situations of transaction costs commented above. Results indicate a similar path for all costs scenarios, reaching maximum transfers for λ=0.5 in every case. However, we must indicate that, as it is logical, the amount of transfers decrease when transaction costs are higher. For example, water transfers at maximum level with no costs exceed in 8 percent to the initial costs situation, whereas with duplicated costs, transfers are reduced by 25 percent.

The same trend is also reflected in aggregated gross margin and in total labour demand levels (figures 3 and 4). For different values of λ, aggregated margin without transaction costs reaches around 15 percent over the aggregated margin with initial costs, with an average increase in total labour demand of 15 percent, whereas with a double level of costs aggregated gross margin is on average 16 percent below the initial one, with a loss of total labour about 17 percent.

These results show the convenience of improving the legal framework that establishes the water market to make transaction costs as low as possible. Only with this condition the economic and social benefits can be optimised under a market situation.

5 CONCLUDING REMARKS

The most important conclusions obtained form this research are twofold. From the methodological point of view, is convenient to emphasize the advantages that proposed MCDM approach has. Indeed, like it has been verified through the validation of the models that simulate the producers' individual behaviour (models [8]), the different productive decisions they take (crop mix and input use) cannot be explained by assuming a profit maximization behaviour and only considering differences in their structural characteristics (climate, soil, etc.) and in their inputs availability (machinery, production quotas, etc). In order to correctly simulate the behaviour of these decision makers it is necessary consider the different utility functions that they have in a multi-criteria framework. Assuming the necessity to analyse farmers' decision making within the MCDM paradigm, is evident that water use (allocation to different crops and/or its transfer in the market) depends on the *utility* that this input provides to them (contribution to MAUF value: achievement of the different objectives that farmers try to simultaneously optimise), and not only on its *productivity* (profit generation). In this sense we think water markets modelling is more realistic when assuming that water reallocations are produced from the smaller utility generating uses towards those than generate a greater utility, until an equilibrium point is reached when marginal utilities provided by water to all users are equalled to the market price, once discounted the transaction costs. This utilitarian approach supposes an extension of the Classic Economic Theory, that assumes, as a particular case, that only profit maximisation is kept into account as unique management criteria, and defines the market equilibrium when the value of the water marginal product for all the uses are equal to the market price.

With regard to the developed case study it is worth mentioning the interest of the mathematical model built for a better knowledge and modelling of water markets in the real world. From the results obtained, some interesting practical conclusions can be also reached. In this sense the most important one is the significant potential of water markets as a demand policy instrument to increase economic efficiency and agricultural labour demand, specially in water scarcity periods. Results obtained confirm this positive impact from the economic and social points of view. These gains are due to transfers made towards those producers with more commercial profiles (greater w_{TGM}), with greater competitive advantages (favourable soil and climate conditions) and with better geographic locations (downstream).

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