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Supply uncertainty and the economic value of irrigation water

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Abstract

The economic value of irrigation water to horticultural producers in southern Spain is examined using a choice experiment. Marginal water values are found to be typically above those currently paid and to increase with holding size. Potential gains from trade are identified but this would entail the transfer of water and production from smaller to larger holdings. Uncertainty in future irrigation water allocations is also examined. We find producers to be strongly risk averse in their preferences towards water allocations, with significant heterogeneity in the valuation of reduced uncertainty regarding future water allocations.

Keywords: choice experiment, irrigation, water, willingness to pay

JEL classification: Q25, Q15, Q12, Q51

1. Introduction

Rising water demands are difficult to meet in many regions of the world. This growing scarcity focuses attention on the allocation of water between competing uses, with water pricing increasingly advocated as a means of 'improving' water allocations and promoting water conservation.

Agriculture, particularly irrigated agriculture, is one of the biggest users of global water supply: some 70 per cent of all water withdrawals are for agriculture (World Meteorological Organization, 1997). In Europe, agriculture accounts for 40 per cent of water withdrawals (Revenga, 2000). Irrigated agriculture accounts for 40 per cent of global food production, even though it represents just 17 per cent of global cropland (World Meteorological Organization, 1997). When trade-offs between sectors competing for water are considered, it is usually (irrigated) agriculture that is thought to be the

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low-value sector and therefore to be the default source of increased re-allocations to urban sectors (Young, 2005: 162).

This paper is concerned with the economic value of water to irrigation producers in southern Spain. The issue is of importance because of the ongoing water crisis in Spain (discussed in Section 3), where the issue of water and its transfer between uses and regions has reached a prominence almost unheard of in Europe. A choice experiment (CE) is the method used to identify the marginal value of water to irrigation farmers. This approach has been very rarely used in this context in general and this study is (we believe) the first use of a CE to identify marginal values for irrigation water in Europe. Using a CE approach to value irrigation water has a number of advantages. First, it allows one to control multiple dimensions of the water commodity simultaneously (for example, quantity and security of supply and interactions thereof) and hence implicitly enables one to explore a wide range of the preference space. Second, it allows one to parsimoniously identify heterogeneity in preferences within that space, either through the inclusion of individual or farm characteristics, or through the use of random parameters. These techniques allow the retrieval of distributions of preferences and hence marginal economic values for water associated with differing security of supply. Given that it is heterogeneity in value that leads to gains from trade, the quantification of this variation is particularly valuable.

We identify strong variability in marginal willingness to pay (WTP) for water among the surveyed irrigators. Farm size and access to groundwater are found to significantly affect the marginal value of irrigation water. Given the identified variability in WTP, an assessment of the potential scale of the gains from trade within the irrigation community (IC) is given. Finally, we examine uncertainty in water supply and the risk preferences of producers – analysing how the choice of irrigation contracts offered in the experiment is affected by the levels of both guaranteed and uncertain water allocations they include.

The structure of the paper is as follows. Section 2 locates the study within the literature on the economic value of (irrigation) water and the methods used to investigate it. In this section, previous economic analyses of the potential impacts of irrigation water trading in Spain are discussed. Section 3 briefly reviews the water crisis in Spain and the transfer of water from the Tajo to the study area: the Segura Basin. The experimental design, survey and resulting data are described in Section 4, while Section 5 contains the results and discussion. Section 6 concludes the paper.

2. The economic value of irrigation water

Reviews of the approaches to estimating the economic value of water can be found in Young (2005) and with regard specifically to irrigation water in Tsur and Dinar (1995, 1997), Johansson (2000), Johansson *et al.* (2002) and Tsur *et al.* (2004). Young (2005: 47) classifies the methods for determining the economic value of water into two main groupings: deductive and inductive.

Deductive methods involve the derivation of shadow prices where water is an input into production systems. Inductive methods comprise valuations based on observed behaviour in real markets or production settings, usually when the public good aspects of water are being considered. The use of stated preference methods to investigate the economic value of water has more typically been concerned with its public good aspects, such as the value of recreational waterways. They are less common concerning the use of water in agriculture.[1]

2.1 The economic value of irrigation water in Spain

The use of deductive methods and particularly programming models based on multi-attribute utility theory have dominated the empirical investigation of the value of irrigation water in Spain and the likely impacts of water trading. Most of the studies use programming methods in which the goals of total gross margin (TGM) maximisation and the minimisation of both risk (variance in TGM) and the purchase of labour inputs appear in the objective function.

Gómez-Limón and Berbel (2000) use this multi-criteria programming approach to analyse the impacts of water pricing in the Duero Valley in northern Spain, Berbel and Gómez-Limón (2000) use the same approach for farms in the mid-Guadalquivir and Duero Valleys, while Gómez-Limón *et al*. (2002) employ the approach to examine related water-pricing scenarios in northern Spain. Arriaza *et al*. (2002) use a similar approach to analyse water trades between three types of producer (small, medium and large) and find that trading leads to water transfers from the medium and large producer to the small producer. Pujol *et al*. (2006) analyse the likely effects of irrigation water markets in six areas of Catalonia, finding that water trades lead to water being transferred from cropping enterprises to livestock and fruit operations. The approach in Calatrava and Garrido (2005) is somewhat different to the preceding papers in that the focus is on the role of uncertainty in irrigation water markets.

Stated preference approaches have been absent with two exceptions. Calatrava Leyva and Sayadi (2005) conduct a contingent valuation (CV) study among a sample of 64 tropical fruit growers in Granada. While growers are observed to pay an average of EUR 0.14/m^3 and a maximum of EUR 0.19/m^3 for irrigation water, the equivalent WTP figures from the CV study are EUR 0.27/m^3 and EUR 0.60/m^3, respectively. The same study estimates the average marginal income value of water to be between EUR 1.52/m^3 and EUR 1.62/m^3. Colino Sueiras and Martínez Paz (2007) also use a CV approach in which farmers in Murcia are asked an open-ended CV question regarding the maximum additional amount they would pay for their irrigation water. The authors find irrigators paying an average of EUR

[1] Indeed, Young's chapter on 'Valuation of water used in irrigated crop production' includes no mention of stated preference techniques, with the emphasis firmly on applications using deductive methods.

0.21/m^3 and a maximum of EUR 0.40/m^3, with the mean and maximum WTP values EUR 0.43/m^3 and EUR 0.95/m^3, respectively.

The use of a CE to investigate the marginal value of irrigation water is extremely uncommon and restricted to two published studies outside Europe. Crase *et al*. (2002) conducted a CE among farmers with extractive water rights in New South Wales, Australia, while Kunimitsu's (2006) CE study in Japan asked farmers to choose between paddy fields which varied in terms of their rent, the quantity of water they had access to and their distance from the farm. Some other CE studies feature irrigation, but only indirectly, and they do not derive marginal values of irrigation water (for example, see Hope, 2006; Barkmann *et al*., 2008).

3. The Spanish water crisis and the Tajo–Segura transfer

Increasing scarcity of water between competing uses has propelled the issue of water and its allocation high onto the political and social agenda in Spain, most notably with the rise and fall of the Ebro Transfer (Albiac *et al*., 2006). The 2001 National Hydrological Plan (NHP) proposed the annual transfer of 1,050 hm^3 from the Ebro in the North to 'water deficit' catchments in the south of Spain, with most of it intended for irrigated agriculture (Ministerio de Medio Ambiente, 2000). The Ebro Transfer proposed in the NHP, withdrawn following the 2004 election, prompted marches in excess of 100,000 people in major cities, an unprecedented response to water policy in a developed country. The withdrawal of the Ebro Transfer leaves existing large-scale water transfers, such as the Tajo–Segura transfer, which supplies water to the IC studied in this paper, under scrutiny (World Wide Fund for Nature, 2003, 2004). This poses problems for the irrigated farming sector in Spain since it has grown rapidly (the irrigated area has increased by 51 per cent between 1990 and 2003; Aquastat, 2009), yet that growth has occurred in some of the driest parts of the country, many of which are reliant on water transfers.

The framework that governs the allocation of water between sectors and regions in Spain is characterised by state-managed supply control. There have been very tentative steps towards water trading among irrigators in recent years, but little formal water trading is occurring. The possibility of legal but restricted, voluntary water exchanges was introduced by the 1999 reform of the Water Act. The water markets the 1999 Act aimed to instigate, largely failed to appear, possibly because of the widespread distrust of formal water markets among farmers. Fears that formal markets would increase monitoring, taxes and corruption appear to be dominating the lure of potential gains from trade and, in the midst of a drought, it may be feared that a willingness to sell water may be seen as sending a signal that the water is not really needed (Albiac *et al*., 2006). However, informal spot trading at the local level is common in the southeast of Spain among farmers in the same irrigation district. Although the prospect of a more market-based approach to pricing has increased since the introduction of the Water Framework

Directive (European Commission, 2000), and while there have been reforms aimed at 'timidly encouraging temporary exchanges of water use rights' (Albiac *et al.*, 2006: 740), market mechanisms are largely excluded from water allocation systems in Spain (Irujo, 2007).

This study analyses the marginal value of irrigation water transferred to the Campo de Cartagena IC in the Segura Basin from the Tajo river in the middle west of Spain. The water supply in southeast Spain has been augmented with water from the Tajo river since 1978. The geographic scale of the channel used is shown in the first panel of Figure 1. On average, 22 per cent of the water diverted from the Tajo is used for domestic supply and 78 per cent for irrigation.

The two factors shaping the irrigation allocations are availability (a function of rainfall) and demand from other sectors. Figure 2 shows annual quantities of water, for urban and irrigation use, coming from the Tajo between 1978 and 2006. These allocations have fluctuated with drought in 1982–1984 and 1992–1995, and the allocation to agriculture plummeted from 2005–2006. The target amount of irrigation water transferred from the Tajo is 400 million m^3. If the amount available is below this, then the allocations to ICs and their members are reduced in proportion. The transfer of water from the Tajo to the Segura Basin is based on a specific Act (Law 52/1980), with the quantity of irrigation water each farmer receives depending on their area under management. Annual variations in the tariff for Tajo water are also shown in Figure 2. The average Tajo water tariff since 1978 is EUR 0.096/m^3, but drought pushed the tariff to EUR 0.16/m^3 in the late 1990s. The tariff between 2006 and 2009 has been EUR 0.12/m^3. This tariff comprises amortisation costs and fixed and variable cost of operation and

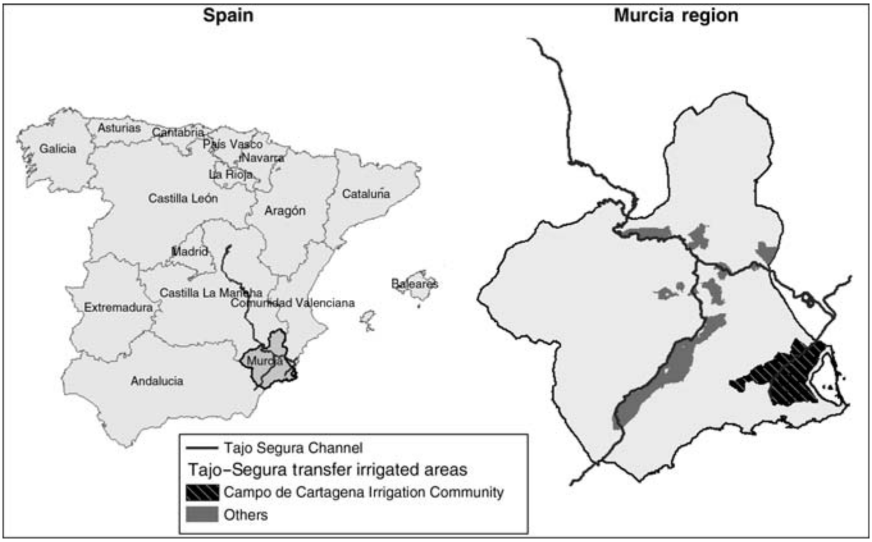

Fig. 1 The Tajo–Segura channel and the Campo de Cartagena IC.

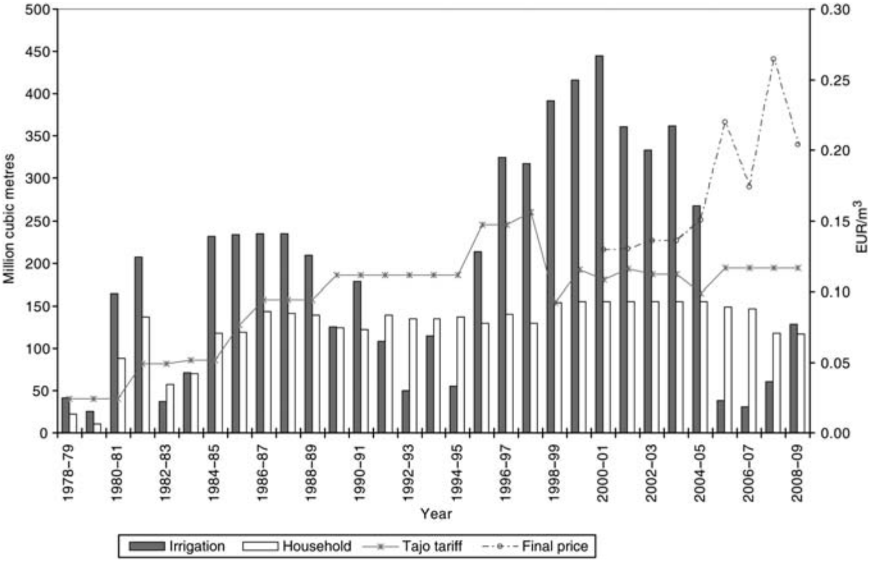

Fig. 2 Tajo water allocations and tariffs in the Segura Basin, 1978–2009.
Source: Tajo-Segura Aqueduct Irrigator Central Union (TASICU) (2008) and Comunidad Autónoma de la Región de Murcia (CARM) (2007).

maintenance but is not the full price paid by the irrigator. The final price the farmer pays includes a series of levies to cover the investment, operational and maintenance costs of the IC. At the time of the data collection for this study (2005–2006), these levies amounted to EUR 0.10/m^3, pushing the final price paid by farmers to EUR 0.22/m^3. These final prices (for recent years) are also shown in Figure 2, revealing that in 2007–2008, the price paid by irrigators peaked at EUR 0.26/m^3.

Variable and insufficient allocations have led many farmers to use groundwater to make up shortfalls in supply, although not all have access to it, and new boreholes have been banned in the region by Royal Decree since 1986. A World Wide Fund for Nature report (2006) estimates the number of illegal wells in Spain to be about 510,000, with at least 3,600 hm^3 of groundwater extracted illegally each year. The effects are declining water levels, increasing salinity levels and growing energy cost of extraction. It is estimated that the average cost of groundwater extraction is around EUR 0.21/m^3 but can reach up to EUR 0.74/m^3 in extreme situations (Ministerio de Medio Ambiente, 2003, 2007).[2] The salinity problems related to groundwater-irrigated agriculture are found in many other regions of Spain (Andalucía, Aragón, Castilla y

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[2] The quality of groundwater is typically poor, and, *ceteris paribus*, its salinity renders it less preferable compared with transferred surface water. Farmers in the Segura Basin often have to mix water from the two sources in lagoons in order to create water of sufficient quality to apply to their horticultural crops.

León, etc.) and elsewhere in southern Europe (for a review of the environmental impacts of irrigation, see Baldock *et al*., 2000).

4. Experimental design, survey and data

The study area is the Campo de Cartagena IC. It is the largest single IC in the Segura Basin and one of the largest in Spain. It receives approximately 30 per cent of all the irrigation water diverted from the Tajo. The location and scale of this IC is shown in the second panel of Figure 1. It was comprised, in 2006, of about 32,800 ha of irrigated land on which vegetables (51 per cent), citrus fruit (35 per cent) and fruit trees (8 per cent) were grown (CARM, 2007). Drip irrigation dominates this system and 95 per cent of the irrigation water comes from the Tajo (TASICU, 2008). The survey was conducted at the IC's 10 offices as farmers arrived to book their water needs for the following week. In the course of the interview, respondents were presented with a series of hypothetical contracts for the following four years' supply from the IC.

The attributes comprising the contract (Table 1) included the amount of guaranteed water provided annually and the price per cubic metre. The mid-level of the guaranteed water attribute was set at the 10-year average allocation (3,000 m^3/ha). The prices used (0.15, 0.25, 0.40 EUR/m^3) were, similarly, approximately centred on the price being paid by irrigators at the time (EUR 0.22/m^3). We also sought to investigate supply uncertainty and risk preferences of irrigators. When farmers invest (in buildings and equipment and plant crops, especially perennial crops), they are making judgements about future allocations of water over several years. While their allocations had been relatively stable over the preceding 10 years, there were still significant fluctuations (the allocations for the previous two years had been about 3,362 and 2,492 m^3/ha), and at the time of the survey (2006), it was becoming apparent that the corresponding year's allocation would be very low (Figure 2). To explore preferences regarding uncertain water allocations, a third attribute indicated an additional quantity of water. However, the provision of this additional water was uncertain, with the final attribute indicating the circumstances under which this water would be released. This was specified in terms of a rainfall level, as well as the associated probability of these rainfall levels occurring. These probabilities represented, therefore, the probability the additional water specified in the contract would be delivered.

Table 1. Attributes and their levels

Attributes	Variable name	Units	Levels
Guaranteed water	guaranteed	(m^3/ha year)	2,000, 3,000, 4,000
Additional water	additional	(m^3/ha year)	1,000, 2,000
Probability of additional water	prob	Probability	0.5, 0.25
Price	price	(cent €/m^3)	15, 25, 40

On the basis of 50 years of rainfall data, the probabilities associated with the attribute levels were: rainfall over 200 mm (50 per cent) and rainfall more than 300 mm (25 per cent).

The study employed a full factorial CE design. This is unlike most studies which use a 'main effects' design to reduce the numbers of options and interviewee choices. A powerful assumption underlying the analysis of data from such main-effects designs is that the marginal utility of a particular attribute is independent of the levels of all other attributes. In this case, this assumption was expected to be violated given the roles of guaranteed water, additional water and probability of additional water (via the rainfall threshold) in the contracts offered. A full factorial allows all possible interaction terms between attributes to be identified. The full factorial design provided 36 different contracts, which were combined into 12 choice sets with three contracts presented in each of them. Because of concerns raised in pretesting about the willingness of landholders to answer a large number of choice questions, the 12 sets were blocked into 6 groups, with each respondent presented with 2 choice sets. Following piloting and questionnaire revisions, a total of 213 farmers were interviewed, yielding 426 completed choice sets, distributed evenly across the blocks. Demographic and farm details were recorded along with contract choices.

An atypical feature of the design was the absence of a 'none' or '*status quo*' option. There are advantages and disadvantages of using such a forced choice approach. Using forced choices without an opt-out alternative may increase the cognitive burden on respondents; however, an opt-out may be (serially) selected as an easy escape route from the cognitive burden of the task (von Haefen *et al.*, 2005; Burton and Rigby, 2009). Kontoleon and Yabe (2004) discuss how the use of an opt-out may, in this way, distort the incentives for true preference revelation (see also Carson *et al.*, 1999). Consequently, whether an opt-out is preferable in survey design is not always clear cut, and the impacts of (in/ex)clusion can be examined empirically (see Kontoleon and Yabe, 2004; Carlsson *et al.*, 2007).

In addition, there are implications of a forced choice design for the conclusions one can draw about welfare changes. Marginal values of attributes could not be estimated if even the 'best' of the forced choices implied a catastrophic consequence for the respondent if it were to be executed. An example in this case would be if all contracts were so punitive in the water price that they implied bankruptcy if implemented. Given the attribute levels used in this study, we think this extreme outcome is unlikely. The mean levels of expected water offered in the contracts were over 3,500 m^3/ha, above the long-term average allocation, while the mean minimum price in the contracts was EUR 0.20/m^3 at a time when EUR 0.22/m^3 was being paid. Given the extraction costs and poor quality of the groundwater (discussed in Section 2), it is unlikely that the preference would be to revert to using it alone, and the alternative of ceasing irrigated production is – at the range of prices used in the survey and the value of the products being produced – also extremely unlikely. We found no evidence in the piloting

Table 2. Farmer and farm characteristics

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Age	213	51.51	12.79	20	82
Experience	213	31.44	14.56	4	64
Study	213	0.55	0.77	0	3
Area	213	19.84	42.26	0.11	420
Groundwater	213	0.85	0.36	0	1
Cooperative	213	0.50	0.50	0	1

Note: Variables are defined as follows: age, years; experience, years; study, no studies (0), left education at 14/16 (1), left education at 18 (2), university study (3); area, farm area (ha); groundwater, access to groundwater on farm (0,1); cooperative, member of a cooperative (0,1).

or the main survey of farmers expressing any view that they would prefer to reject all the contracts in a choice set. Given the drought, increasing prices and uncertainty regarding future allocations, the impression was that the contracts in the survey would be welcomed.

Turning now to the data collected, the characteristics of surveyed farmers (Table 2) reveal that they are typically highly experienced (mean of 31 years in farming, mean age 52), with most of them living on the farm. These age and experience levels, as well as the content of the interviews themselves, provided confidence that interviewees had a good awareness of rainfall levels over a long period and hence could interpret the probability attribute accordingly. Levels of education were low, with 60 per cent of the sample having no formal qualifications and only 2 per cent having studied at university.

In terms of the farms themselves, the cropping area averaged 20 ha, with the most frequent farm size between 1 and 5 ha. Most of the small farms use greenhouses to generate high yields based on intensive water usage. Just under a fifth of the farms are greater than 30 ha. There are many trading cooperatives orientating on the export market in the area, and half the farmers are members of such cooperatives. Water scarcity has prompted 85 per cent of farmers to augment their irrigation water supplies via groundwater.

5. Results

We start from what we refer to as the *General* model based on a utility function involving attribute levels and interactions between them:

$$\begin{aligned} U_{ij} = {} & \beta_1 \text{guaranteed}_j + \beta_2 \,\text{prob}_j \cdot \text{additional}_j + \beta_3 \,\text{prob}_j + \beta_4 \,\text{price}_j \\ & + \beta_5 \text{guaranteed}_j \cdot \text{ price}_j + \beta_6 \,\text{prob}_j \cdot \text{additional}_j \cdot \text{ price}_j \\ & + \beta_7 \text{additional}_i + \beta_8 \cdot \text{additional}_j \cdot \text{guaranteed}_j + e_i. \end{aligned} \tag{1}$$

We then consider restricted forms of this utility function. The first, labelled the *Attributes* model, takes the form:

$$U_{ij} = \beta_1 \text{guaranteed}_j + \beta_2 \text{additional}_j + \beta_3 \,\text{prob}_j + \beta_4 \,\text{price}_j + e_i. \tag{2}$$

The significance of this model is that it might be viewed as the canonical specification for a conditional logit (CL) model, assuming that the latent utility function is a linear function of the four attributes.

The second restricted specification is more parsimonious and is intuitively driven by the relationship between the probability of additional water being delivered (prob) and the amount of that additional water (additional). This specification combines the attributes to describe the contracts offered in terms of the expected amount of water delivered (exwater) and the expected cost of the contract (excost). We refer to this as the *Expected Levels* model:

$$\begin{aligned} U_{ij} = {} & \beta_1[\text{guaranteed}_j + \text{prob}_j \cdot \text{additional}_j] + \beta_5[\text{guaranteed}_j \cdot \text{price}_j \\ & + \text{prob}_j \cdot \text{additional} \cdot \text{price}_j] + \beta_3 \,\text{prob}_j + e_i. \end{aligned} \tag{3}$$

which can be described in more intuitive terms as:

$$U_{ij} = \beta_1 \text{exwater}_j + \beta_5 \text{excost}_j + \beta_3 \,\text{prob}_j + e_i. \tag{4}$$

Note that the prob term is present in this specification to allow for a residual preference for higher probabilities of delivery of water, over and above that captured by prob·additional. If respondents are risk-neutral and weighting the levels of additional water in the contracts according to the probability of the rainfall thresholds being passed, then the prob term will have a zero value giving a final, more restricted specification:

$$U_{ij} = \beta_1 \text{exwater}_j + \beta_5 \text{excost}_j + e_i. \tag{5}$$

The empirical approach involves estimating models of the form shown in equations (1) to (5) and testing the restrictions involved in moving from the general to more parsimonious specifications.[3] This estimation and testing process is undertaken for both CL and mixed logit (MXL) models.

The CL model is based on McFadden's (1974) implementation of the random utility model with a linear utility function and Gumbel distributed error terms. This allows the probability of respondent *i* selecting contract *j*,

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[3] Questions as to whether all these models were identified, given the design and sample size, were raised in the refereeing process. This was addressed using bootstrapping analyses and *ex post* design evaluations using *Ngene*. Model results were stable and the models were identified. Results of this evaluation are available on request.

P_{ij}, to be expressed as a CL of the form:

$$P_{ij} = \frac{\exp(\mu V_{ij})}{\sum_{k=1}^{K} \exp(\mu V_{jk})} \tag{6}$$

in which $V_{ij} = \beta' X_j$ represents the deterministic part of the indirect utility expression in equation (1), k represents the number of contracts for a farmer to choose between in each choice set ($K = 3$) and μ is the scale parameter which is typically normalised to 1 (for more on the implications of this assumption of a uniform scale parameter, see Louviere and Eagle, 2006).

The mixed logit model has become common since the model was established and developed (Revelt and Train, 1998; Train, 1998; recent applications include Rigby and Burton, 2005; Carlsson *et al*., 2007). In this model, preferences vary randomly over individuals, and respondents' choices are conditional on the specification of the distribution of the coefficients. Defining the distribution of the β parameters by a vector of parameters φ (typically the mean and variance of an assumed distribution), the probability of individual i choosing contract j, $P_{ij}^{\sim}$, becomes:

$$P_{ij}^{\sim} = \int P_{ij} f(\beta|\varphi) \mathrm{d}\beta, \tag{7}$$

where $f(\beta|\varphi)$ is the probability density function for β defined over a vector of parameters φ. The log-likelihood (LL) function is given by

$$\sum_{i=1}^{N} \sum_{j=1}^{J} d_{ij} \ln\left(P_{ij}^{\sim}\right), \tag{8}$$

where d_{ij} is an indicator with value unity if person i chose contract j and 0 otherwise. Given the absence of a closed form for equation (6), $P_{ij}^{\sim}$ is simulated according to the density $f(\beta|\varphi)$, where the simulated LL is

$$\sum_{i=1}^{N} \sum_{t=1}^{T} \sum_{j=1}^{J} d_{itj} \ln(P_{itj}^{\#}) \tag{9}$$

in which $P_{itj}^{\#}$ is the simulated probability where t denotes choice task t.

Table 3 summarises the estimation results for the three utility functions in equations (1) to (3), for both CL and MXL models.[4] We first consider whether, for each specification, the MXL model can be restricted to its CL form, that is,

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[4] In the case of the mixed logit models, we start with the most general specification with all terms random (and normally) distributed.

Table 3. Model selection

	Unrestricted model	Restricted model	LR tests	
			$2 \cdot \Delta LL$	$\chi^2_{\text{crit value, 5 per cent}}$
Models	MXL_{gen}	CL_{gen}		
LL	−240.311	−250.999	−21.376	15.51
Parameters	16	8		Reject restrictions
Models	MXL_{attrib}	CL_{attrib}		
LL	−246.406	−253.975	−15.1388	9.49
Parameters	8	4		Reject restrictions
Models	MXL_{expect}	CL_{expect}		
LL	−245.191	−255.115	−19.8466	7.81
Parameters	6	3		Reject restrictions
Models	MXL_{gen}	MXL_{attrib}		
LL	−240.311	−246.406	−12.1884	15.51
Parameters	16	8		Accept restrictions
Models	MXL_{gen}	MXL_{expect}		
LL	−240.311	−245.191	−9.7596	18.31
Parameters	16	6		Accept restrictions
Models	MXL_{expect}	$MXL_{expect*}$		
LL	−245.191	−297.47	−104.555	18.31
Parameters	6	4		Reject restrictions

Note: The *General*, *Attributes* and *Expected Levels* models (from equations (1)–(3)) are denoted by the gen, attrib and expect subscripts, respectively. $MXL_{expect*}$ denotes restricted model in equation (5) in which the prob term is removed from the *Expected Levels* model.

whether the restriction that all terms are fixed is accepted by the data. As Table 3 shows, this is not the case since likelihood ratio (LR) tests reveal a rejection of the restrictions (and hence the CL model) for the *General, Attributes* and *Expected Levels* models.

We next consider which of the three models is preferred in the mixed logit form. The *General* model nests the *Attributes* and *Expected Levels* models and so a series of restrictions can be imposed and tested. Referring to the utility function in equation (1), moving from the *General* to the *Attributes* model implies that $\beta_2 = \beta_5 = \beta_6 = \beta_8 = 0$. Moving from the *General* to the *Expected Levels* model implies that: $\beta_1 = \beta_2$, $\beta_5 = \beta_6$ and $\beta_4 = \beta_7 = \beta_8 = 0$. As Table 3 shows, both these sets of restrictions are accepted for the MXL model.

Finally, we compare the MXL forms of the *Attributes* and *Expected Levels* models. These are not nested and hence we use the following information criteria: Akaike's (1973) information criterion (AIC), the modified or Bozdogan's AIC (AIC3, Bozdogan 1987), Schwarz's Bayesian information criterion (BIC, Schwarz, 1978) and Bozdogan's (1987) Consistent AIC (CAIC). The AIC, AIC3, BIC and CAIC criteria support the *Expected Levels* over the *Attributes* model and hence the MXL specification of the

Table 4. Preferred mixed logit models, with and without farm characteristics

	Without characteristics			With characteristics		
	Coefficient	Standard error	z-Value	Coefficient	Standard error	z-Value
Random terms						
exwater mean	0.0028	0.0003	9.04	0.0016	0.0004	3.93
exwater standard deviation	0.0013	0.0003	4.99	0.0008	0.0003	3.11
Fixed terms						
excost	−0.0615	0.0060	10.22	−0.0785	0.0081	9.64
prob	8.2135	0.9640	8.52	7.7406	0.9130	8.48
excost·lnarea				0.0088	0.0020	4.36
Heterogeneity in mean of random term						
exwater·groundwater				0.0012	0.0004	2.82
	$N = 426$, LL $= -245.4863$			$N = 426$, LL $= -225.3894$		

Note: The excost data have been rescaled for estimation purposes and are in units of EUR 10.

Expected Levels model is preferred. An additional restriction on the *Expected Levels* model, shown in equation (5), is that $\beta_3 = 0$, and hence prob plays no residual role in contract choice. This restriction is rejected.

Finding that the *Expected Levels* model is preferred means that one can integrate the attributes into meaningful measures of *expected water* and *expected cost*, but, in addition, the probability of receiving additional water has an additional impact on choices. Although the MXL model allows all parameters to be randomly distributed, empirically some may be represented as fixed. Additional LR tests reveal that one can restrict the mixed logit *Expected Levels* model further by constraining the excost and prob terms to be fixed rather than random terms.[5] It is this model that is presented in the first panel of Table 4.

A primary motive for the study is identifying the value of irrigation water to producers given the non-market mechanisms by which allocations and costs are determined. Further, heterogeneity in value is of real interest given the hypothesis that efficiency and marginal valuations differ across producers, something that the current system does not take into account. Therefore, in addition to the heterogeneity associated with the random term on excost, the role of farm and farmer characteristics in further modifying marginal utilities was investigated. Two farm characteristics were found to play a significant role in choices made: the log of the farm cropping area (lnarea) and whether the farm had access to groundwater (groundwater). The former is found to significantly affect the marginal utility of expected contract cost, while the latter affected the marginal

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[5] LL of −245.49 compared with LL of −245.19 with two extra parameters.

utility from the contracts' level of expected water. No other significant effects were identified.

The second panel of Table 4 shows the results of introducing these characteristics into the mixed logit model. The positive relationship between excost·lnarea indicates that the bigger the farm size, the lower the disutility from increases in the cost of irrigation water: bigger farms are less price sensitive. The relationship between access to groundwater and exwater is accommodated by the former moderating the mean of the distribution of marginal utilities of exwater. The positive coefficient indicates that the marginal utilities for exwater for farms with groundwater are drawn from a distribution with a higher mean than those for farms without access to groundwater. Hence farms with groundwater typically have higher marginal utilities from and, *ceteris paribus*, higher WTP for irrigation water. These relationships are shown in Figure 3 with kernel density plots of the distribution of marginal utilities for exwater for those farmers with and without access to groundwater.

The lower price sensitivity of bigger farms is intuitive if larger farms are more efficient and hence likely to have higher marginal values of water. The expected impact of the groundwater interaction was ambiguous. Groundwater access might have indicated greater flexibility in sourcing water and hence reduced WTP for Tajo water. However, it might also have been an indication that the landholder was engaging in high value production and hence placed a greater value on additional water. We conclude that the effort and cost associated with extracting groundwater can be taken as an indication of producer's greater demand for irrigation water and the potentially higher value product they are able to generate with it.[6]

To summarise, the preferred *Expected Levels* MXL model with characteristics reveals that there is significant heterogeneity regarding the marginal utility of exwater which is amplified by variability in access to groundwater. Farms with groundwater access value irrigation water more highly. Bigger farms are less price sensitive. The prob term is strongly positive and significant but there is no significant variation in the marginal utility of this term. Respondents valued increases in the probability of additional water allocations over and above those captured via the weighting of the quantity of additional water by the probability of it being delivered. The positive and strongly significant prob term indicates strong risk aversion.

We now consider the level of and variability in WTP for irrigation water, which is given by

$$\frac{\beta_{\text{exwater}}}{-\beta_{\text{excost}}}. \tag{10}$$

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[6] Information on levels of groundwater extraction by farmers would have been preferable to the access dummy variable. However, the sensitivity regarding the issue of groundwater use made asking for this information infeasible.

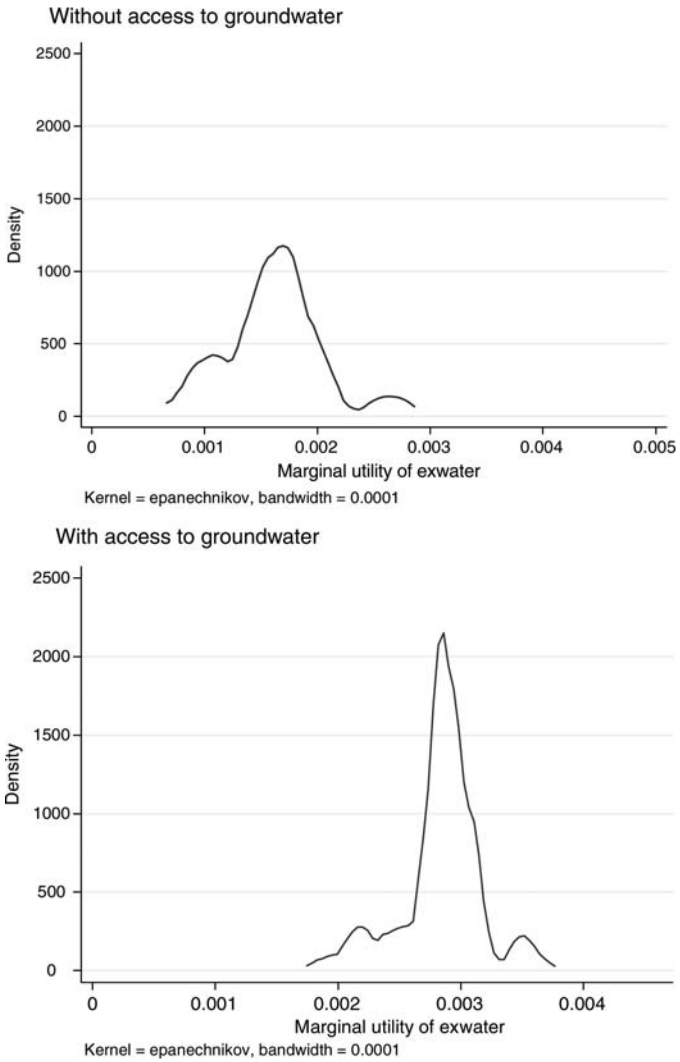

Fig. 3 Kernel density plots of marginal utilities of expected water.

The WTP for irrigation water will be affected by the size of a farmer's holding and whether he has access to groundwater on that holding. The mean WTP for irrigation water in the sample is EUR 0.45/m^3. For those producers who have not sunk bore holes on their land, the WTP/m^3 is in line with what they have paid in recent years at EUR 0.22/m^3, while for those with access to groundwater, the WTP is much higher at EUR 0.50/m^3. Within both these groups, farm size further affects water valuations. Farmers with a farm area below 10 ha have a mean WTP of EUR 0.37/m^3 (EUR 0.41 and EUR 0.22 with and without groundwater). The distribution of WTP values

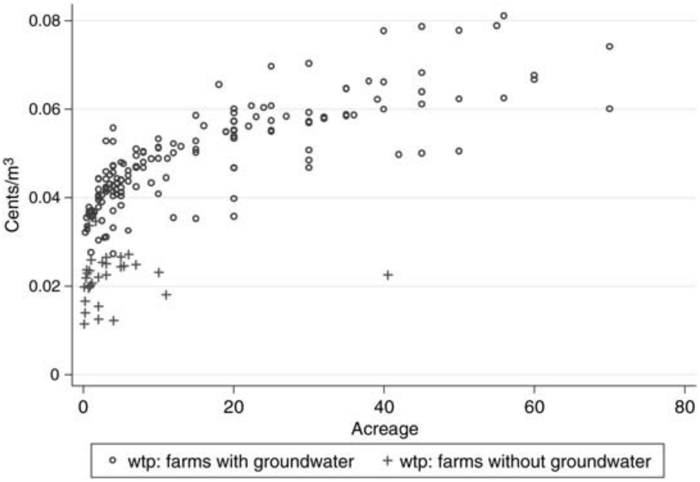

Fig. 4 WTP for irrigation water.

is shown in Figure 4, which reveals the heterogeneity in WTP, affected by both farm size and groundwater access.[7] This heterogeneity in the valuation of irrigation water points to a considerable scope for efficiency gains from water trading, even within this single IC.

The estimated WTP values reported here are larger, but of a similar scale, to those estimated by Calatrava Leyva and Sayadi (2005), whose simulation of water trading gave clearing prices up to EUR 0.30/m^3. Calatrava Leyva and Sayadi's estimate of the marginal value product of water for growers in Murcia was considerably higher at EUR 0.75/m^3, while the average maximum price growers were prepared to pay was EUR 0.27/m^3 with a maximum at EUR 0.60/m^3. Albiac *et al.* (2006) report an estimated average value product of water for agriculture of EUR 0.75/m^3 alongside estimates of water prices of EUR 0.61/m^3 from the proposed Ebro transfer and EUR 0.52/m^3 from the new desalination programme. The results here indicate that WTP for irrigation water is increasing in holding size.

The value of increased certainty in supply contracts can also be identified. Taking estimated marginal utilities from the mixed logit model, the average WTP for an increase in the certainty of uncertain water of 25 percentage points, i.e. an increase in the contract's probability of delivery from 0.25 to 0.5, is EUR 330. There is significant heterogeneity in this WTP value, with the 10th and 90th percentile values ranging from EUR 246 to EUR 428. This suggests variability not only in the marginal valuation of irrigation water but also in the marginal valuation of increased certainty in irrigation water supply. An allocation system that offered farmers contracts with

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[7] The seven farms over 100 ha have been excluded from this plot to make the spread among the mass of values clearer.

varying levels of rainfall thresholds (and hence probabilities) triggering additional water supplies could therefore offer efficiency improvements in water allocations.

The differentials in the marginal valuations of water suggest scope for gains from trade. A simple thought experiment provides some indications of the scale of such gains. Assume that each sampled producer is able to trade only 1 m^3 of water and the market clears among the sample. The clearing price will be the median WTP value of EUR 0.44/m^3. This trade generates an average gain from trade per producer of EUR 0.12/m^3 across the sample. We now consider the gains from trade if exchange occurred across the irrigators in the Segura Basin. We apply the estimate of the gains from trade identified above (EUR 0.12/m^3). We then need to consider the amount of trade over which to aggregate the gains. To this end, we set an arbitrary limit of 5 per cent of water transferred from the Tajo being traded. The reason for imposing this limit is to avoid moving too far from the margin given that it is marginal WTP and marginal gains from trade that have been estimated. The data shown in Figure 2 indicate that the average annual irrigation transfer from the Tajo to the Segura Basin over the past five years is 272×10^6 m^3. Constraining the volume of traded water to be 5 per cent of this total generates gains from trade across the Segura Basin of approximately EUR 1.67 million. The role of holding size in determining WTP for water means that this simulated trade entails a significant transfer of water and production from smaller to larger producers.

6. Conclusions

Given the controversy concerning the distribution of water in Spain and the means by which competing uses for it should be managed, it is useful to identify the value placed upon water by users and the heterogeneity in those values. This paper has investigated the values associated with various aspects of irrigation water used by producers in the southeast of Spain. It has considered not only the value placed on the quantity of water, but the impact of uncertainty in provision on those values. These issues have been investigated using a CE among members of one of the biggest irrigation communities in Spain. A CE approach is particularly apposite because of the interest in different aspects of the irrigation water: the quantity of water supplied, the certainty of that supply and the price of the water delivered. These different dimensions of the farmers' irrigation supply are easily incorporated within the CE design compared with, for example, incorporating them within a CV study. Analysis of heterogeneity in the value placed on increased water supplies and greater certainty of supply, which generate the potential for gains from trade, is easily undertaken within the analysis of CE data through the specification of random parameter models and/or inclusion of farm(er) characteristics within the choice models estimated.

The estimated mean water valuation of EUR 0.45/m^3 is well above EUR 0.26/m^3 being paid in 2007–2008. However, there is considerable heterogeneity in the WTP values, with a mean value of EUR 0.22/m^3 among those farmers without groundwater boreholes on their land and EUR 0.50/m^3 for those that do. Farm size is also found to affect WTP, with those managing larger holdings being prepared to pay substantially more for water. These valuations are on a par with or above the costs to farmers of pumping inferior quality water from aquifers.

Given the climatic conditions in the region, allocations of water are not certain and any contracts are likely to be state-contingent. The prevalence of horticultural and orchard crops in the region means that one would expect farmers to be prepared to pay a premium for more certain water supplies, that is, exhibit risk aversion. The issue of uncertainty is analysed using expectations within the CE wherein additional water quantities are included in the contract, but the availability of this additional water is uncertain and depending on the rainfall level in a particular year. The statistical results confirm that farmers would be prepared to pay a considerable premium to increase the probability of the additional water being delivered (approximately EUR 330 per contract to increase the probability by 25 percentage points). If water trading were to become more prevalent, this would suggest that there is an incentive to design contracts with varying degrees of security of supply and corresponding prices so that economic efficiency in the water market can be further enhanced.

The high levels of and variation in marginal values of water derived from the survey suggest that most farmers would pay more than the institutionally set prices they currently pay for their fixed allocations. They also suggest markedly differing levels of marginal value product among irrigation farmers, leading to scope for efficiency gains if water trading was permitted between and among irrigation communities. A simple simulation exercise suggests that even if water trading is restricted to 5 per cent of Segura Basin producers' allocations from the Tajo, the gains from trade would be substantial at approximately EUR 1.67 million. Given the positive relationship between farm size and WTP identified, such trade within the IC would lead to a transfer of water from smaller to larger holdings. Although the data on which the results presented here are drawn from a single IC and our simulation is restricted to trades within the basin in which it sits, this analysis does give some indication of the potential gains from even such limited trade. Any further, more comprehensive analysis would require an extension of the sample to a broader geographical area. Such an extension of this research appears appropriate since continued Tajo water allocations at levels below their historic average, will increase the pressure for more intra- and inter-IC transfers and trades.

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