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Willingness to pay for improved irrigation water supply reliability: An approach based on probability density functions

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Abstract

In irrigated agricultural systems, the main source of uncertainty to irrigators relates to water supply, as it significantly affects farm income. This paper investigates farmers' utility changes associated with shifts in the probability density function of water supply leading to a higher water supply reliability (higher mean and lower variance in annual water allotments). A choice experiment relying on a mean-variance approach is applied to the case study of an irrigation district of the Guadalquivir River Basin (southern Spain). To our knowledge, this is the first study using parameters of these probability density functions of water supply as choice experiment attributes to value water supply reliability. Results show that there are different types of farmers according to their willingness to pay (WTP) for improvements in water supply reliability, with some willing to pay nothing (44.9%), others (28.6%) with relatively low WTP, and the remainder of farmers (26.5%) having high WTP. A range of factors influencing farmers' preferences toward water supply reliability are revealed, with those related to risk exposure to water availability being of special importance. The results will help to design more efficient policy instruments to improve water supply reliability in semi-arid regions.

Key words: Choice experiment, irrigation water availability, mean-variance approach, preference heterogeneity.

1 Introduction

Irrigators are deeply concerned about uncertainty over water supply, because variation in water supply significantly affects economic decision-making in irrigated agriculture (Kidson et al., 2013). In fact, in semi-arid regions irrigation water availability is the main source of uncertainty for irrigators, as they must take crop-mix selection and other farm management decisions without knowing for certain what their water allotments will be for the next season. Nowadays, these concerns over water supply reliability in agriculture are growing because of the expected impact of climate change.

Considering that most farmers are risk averse (Menapace et al., 2013), under uncertainty regarding irrigation water availability, irrigators' decision-making (optimal input level use) cannot be considered efficient from a social welfare perspective. This is because agricultural production (and thus wealth generation) is lower than under more certain irrigation water availability. In cases where this production gap is leading to high welfare losses, government action aimed at improving water supply reliability may be justified (OECD, 2000), with the ultimate objective being to increase economic efficiency and social welfare, along with stabilizing irrigators' incomes (Rigby et al., 2010).

Traditionally, solutions for securing water supply have focused on the supply side (Gleick, 2000), mainly through the construction of large-scale infrastructures such as reservoirs. However, supply-side policies often do not represent a viable option anymore

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in semi-arid regions. Existing water supply is frequently found to be unable to meet new demand within the basin, since the development of new sources of supply is limited by economic and environmental constraints. In these circumstances, basins are said to be 'closed' (Molle et al., 2010), and new demand has to be met by diverting water rights from primarily irrigators to other users. This considerably increases irrigators' risk exposure with respect to water supply availability. Indeed, closure of river basins has become so common in water scarce regions that policy-makers increasingly explore demand-side instruments, such as modernization of irrigation systems (Berbel et al., 2015), spot water markets (Debaere et al., 2014), drought water banks (Montilla-López et al., 2016), option contracts (Rey et al., 2016), or drought insurance schemes (Pérez-Blanco y Gómez, 2013).

In order to efficiently design demand-side management policies, information on users' preferences for water supply reliability is required. Knowledge on users' willingness to pay (WTP) for improvements in water supply reliability can also help policy-makers to assess the potential of demand-side instruments to achieve a more efficient resource allocation. Despite its increasing policy relevance, only few papers investigate irrigators' WTP for improved water supply reliability comprising, to the authors' knowledge, Rigby et al. (2010), Mesa-Jurado et al. (2012), Bell et al. (2014), and Alcón et al. (2014). Although these studies provide useful insights into the issue of water supply reliability, they also have some shortcomings: i) to a large extent, the valuation scenarios offered secured or riskless amounts of water supply as alternatives to the current situation, which lacks realism; and ii) the amount of water available for irrigation was not considered as a stochastic variable with its own probability density function.

This paper examines irrigators' WTP for improvements in water supply reliability and analyzes influencing factors (socio-demographic, structural and opinions/attitudes). We use the choice experiment method to analyze farmers' preferences toward changes in water supply reliability and apply a latent class random parameter logit model to study preference heterogeneity. Instead of considering the variable water supply reliability as deterministic, i.e., defined as different amounts of 'guaranteed' water leading to unrealistic valuation scenarios, we consider it as a stochastic variable having its own probability density function (PDF) and cumulative distribution function (CDF). Accordingly, the proposed approach aims at estimating WTP for changes in the PDF and the CDF of water supply, including the novelty of directly connecting the attributes of the choice experiment with parameters of PDFs. This theoretical approach was empirically implemented in an irrigation district located in the Guadalquivir River Basin (southern Spain), thus aiming to support policy-makers in the design of more efficient water management instruments that result in a reduction of local irrigators' risk exposure regarding water availability (i.e., enhancing economic efficiency).

2 Case study: Genil-Cabra Irrigators' Community

In Spain, the Water Act of 1985 declared all water resources to be public property administrated by public basin agencies. It was also established that any private use (e.g., irrigation) would be authorized by the State through legal authorization or concession. These water rights are granted for a maximum amount of water to be used annually (water concession) for uses specifically designated in the legal document. However, Spanish public basin agencies have legal capacity to impose restrictions on the volume of water to be used each year (water allotments) depending on the water stored in reservoirs.

The Genil-Cabra IC, located in the Guadalquivir River Basin (GRB, southern Spain), has been selected as case study. It is a large irrigators' community (15,500 hectares) using surface water resources delivered by the GRB agency. The main crops are olives, sunflower, vegetables (mainly garlic and onion), wheat and cotton. The water fees paid by irrigators are calculated based on fixed costs, covering depreciation and maintenance of infrastructures and personnel (147.50 €/ha/year), and variable costs, covering energy consumed for pumping (0.042 €/m³).

As for most of the ICs in the GRB, the Genil-Cabra IC does not commonly receive the water allotments of the legal concession of 5,000 m³/ha/year for which it is entitled. In contrast, water allotments are generally lower, generating a considerable supply gap in most of the years. In fact, the average water use in the past 20 irrigation seasons has been of 2,572 m³/ha/year (51.4% of water concession) with considerable variation demonstrating relatively low levels of water supply reliability. To improve water supply availability and reliability, the IC has seriously contemplated the construction of three irrigation ponds, which were projected at €27M-budget (with 20%/80% private-public co-financing), resulting in an extra-cost per irrigator of around €38/ha/year. However, this project was discarded as a majority of the IC's members rejected it, because they were not willing to bear the increase in farming costs required to finance it.

Water allotment can be considered as a stochastic variable with its own PDF and CDF. From the series of water allotments in Genil-Cabra IC in the period from 1996 to 2015, we have fitted data to several possible distribution functions. The normal distribution function resulted as one of the most accurate to represent variability in water supply, according to the Anderson-Darling (A-D) statistical test. Figure 1 shows the normal PDF and CDF for the data of water allotments in Genil-Cabra IC and exhibits the two parameters characterizing the PDF: location parameter μ , equal to the mean; and scale parameter σ^2 , equal to the variance.

Figure 1 Normal PDF and normal CDF in Genil-Cabra IC (current scenario)

Considering irrigation water supply as a stochastic variable that follows a normal PDF, and assuming that the irrigators' utility function is quadratic, the analysis of these individuals' responses to risk can be modelled with the mean-variance approach (Levy y Markowitz, 1979). The mean-variance approach has been widely proved to be consistent with expected utility theory (Markowitz, 2014), thus providing a sound theoretical framework for analyzing farmers' preferences toward changes in the variable 'water supply reliability' through changes in the parameters of the PDF of water supply (μ and σ^2).

3 Method

3.1 Scenarios setting

The Hydrological Plan for the GRB (CHG, 2015) establishes the concept of ‘quantitative gap’ as the difference between water concession and water allotment in a given demand unit (e.g., an irrigation district), and may be calculated annually, biannually or decennially. Using water allotment data for the period 1996-2015, this gap has been calculated annually for the irrigation district selected as case study (Genil-Cabra IC) to characterize the current scenario. Based on these calculations, three scenarios of improved water supply reliability were simulated: *scenario I1*, *scenario I2* and *scenario I3*, where annual gaps or differences between concession and allotment are reduced each year by 25%, 50% and 75%, respectively, compared to the current situation. These scenarios are used for the analysis of irrigators’ WTP for improvements in their water supply reliability.

Water allotments data resulting from the suggested improvement scenarios were fitted to normal PDFs and normal CDFs. In all cases, data were consistent with normal PDFs as proved with an A-D statistical test. The resulting normal CDFs are shown in Figure 2.

Figure 2 Normal CDFs in Genil-Cabra in current scenario and in the improved scenarios (*I1*, *I2*, *I3*)

Table 1 shows μ and σ^2 parameters of the normal distribution functions fitted for each scenario.

Table 1 Estimated statistics of the PDFs for the different water reliability scenarios in Genil-Cabra IC (m³/ha/year)

Parameters	Current scenario (Status Quo: SQ)	Improvement scenarios		
		Scenario <i>I1</i> (gap -25%)	Scenario <i>I2</i> (gap -50%)	Scenario <i>I3</i> (gap -75%)
μ	2,572	3,179	3,786	4,393
σ^2	741,321	417,316	185,761	46,225

Source: Own elaboration using irrigators’ community data.

3.2 Mean-variance approach

The mean-variance approach was proposed by Markowitz (1952) for financial portfolio selection in order to help investors to maximize the financial asset’s return while minimizing its risk. This theoretical framework has been adopted beyond financial analysis, becoming one of the most widespread approaches in applied economics to model decision-making under risk (Hardaker et al., 2004). But, as far as the authors are

aware, there is no study to date on water supply reliability adopting the framework of the mean-variance approach.

This framework generally assumes that individuals evaluate decisions based on the first two moments of the probability distribution function, the mean and the variance, being the former a direct and positive source of utility to the individuals, while the latter is a direct source of disutility. In particular in our study, a higher mean in water allotments produces an increase in irrigators' utility, while a higher variance of water allotments generates disutility to irrigators because it implies an increase of uncertainty over water supply, considering that irrigators are risk averse.

3.3 Choice experiment

The choice experiment method is a stated preference valuation technique based on Lancasterian consumer theory of value (Lancaster, 1966), with the econometric basis of the approach relying on random utility theory (McFadden, 1974). Hensher et al. (2005) provide an extensive explanation of the method's theory and practice. The choice experiment implemented in the case study analyzed here considered three attributes. Table 2 shows the attributes and levels used for this empirical study.

Table 2 Attributes and levels used in the choice experiment

Attribute	Explanation	Levels
μ parameter	μ parameter of the normal PDF fitting the four scenarios considered of water supply reliability of the irrigation district (i.e., status quo and three scenarios of improvement)	$\mu_{SQ} = 2,572; \mu_{I1} = 3,179; \mu_{I2} = 3,786; \mu_{I3} = 4,393$ (i.e., μ parameter of the normal PDF of the situation where the gap between the allotments and the concession is reduced by 25%, 50%, and 75%, respectively, compared to the current gap)
σ^2 parameter	σ^2 parameter of the normal PDF fitting the four scenarios considered of water supply reliability of the irrigation district (i.e., status quo and three scenarios of improvement)	$\sigma^2_{SQ} = 741,321; \sigma^2_{I1} = 417,316; \sigma^2_{I2} = 185,761; \sigma^2_{I3} = 46,225$ (i.e., σ^2 parameter of the normal PDF of the situation where the gap between the allotments and the concession is reduced by 25%, 50%, and 75%, respectively, compared to the current gap)
Monetary attribute (Cost)	Yearly additional payment to improve water supply reliability paid by the farmer	2%, 5%, 10%, 20%, 30%, 50% (€/ha/year) of current total payment for irrigation water

Source: Own elaboration.

The two non-monetary attributes directly associated with water supply reliability are the parameters of the normal PDF (μ and σ^2) of water supply reliability. Thus, the levels of these attributes represent possible changes in the PDF for water supply reliability in the irrigation district. For this purpose, attribute levels considered are linked to the changes referred to the abovementioned scenarios of improved water supply reliability, in addition to the PDF for water supply of the current situation.

The monetary attribute consisted of a yearly additional payment to improve water supply reliability. The monetary attribute levels were defined in relative terms of current average expense for irrigation water (€255.5/ha/year), using six levels, corresponding to the following absolute terms (after rounding): €5, €10, €25, €50, €75 and €125 per hectare and year.

A total sample of 205 irrigators in Genil-Cabra IC was interviewed, representing 13.1% of all farmers in the irrigated district. Of these irrigators, five were considered to be protest responses and four were omitted from the sample due to low level of comprehension, hence reducing the total number of valid questionnaires used in the analysis to 196.

3.4 Econometric specification

To incorporate preference heterogeneity into choice modelling, the latent class random parameter logit model (LCRPLM) was used. LCRPLM is a combination of random parameter logit and latent class models, allowing for variation of the parameter vector within and between classes (Greene y Hensher, 2013). Latent class models are well suited to investigating respondents' preference heterogeneity if a considerable richness in the structure of preferences is present that supports the hypothesis that there are a number of discrete latent classes, which would otherwise be unobservable (Scarpa y Thiene, 2005). Overall, the LCRPLM can be very useful when heterogeneous preferences are analyzed, especially for extracting policy implications.

The LCRPLM includes two layers of heterogeneity. One relates latent classes, where it is assumed that individuals are implicitly sorted into a set of s classes. The other relates to random parameters, with the underlying assumption that, within each class, individuals' preferences may vary following a random distribution. The latent class aspect of the model is given as (1) and (2), while the within-class heterogeneity is structured as (3) and (4) (Greene y Hensher, 2013):

$$f(y_i|x_i, s) = g(y_i|x_i, \beta_{i|s}) \quad (1)$$

$$\text{Prob}(s) = \pi_s(\theta), \quad s = 1, \dots, S \quad (2)$$

$$\beta_{i|s} = \beta_s + w_{i|s} \quad (3)$$

$$w_{i|s} \sim E[w_{i|s}|X]=0, \text{Var}[w_{i|s}|X]=E_s \quad (4)$$

where y_i is the vector of choices made by the individual i , x_i is the vector of attributes and $\beta_{i|s}$ the parameter vector which vary among classes and individuals within each class (with β_s and $w_{i|s}$ representing the two terms, respectively), $\pi_s(\theta)$ stands for the probability of membership to class s , X represents the observed data on exogenous variables, and E_s is the covariance matrix for each class.

The contribution of individual i to the log likelihood for the model is obtained for each individual in the sample by integrating out the within-class heterogeneity and then the class heterogeneity. Considering a panel data setting (with y_i , and X_i), with each individual assumed to engage in T_i choice situations (with $T_i > 1$), the generic model is:

$$\text{Prob}(y_i|X_i, \beta_s, \theta, \Sigma_s) = \sum_{s=1}^S \pi_s(\theta) \int \prod_{t=1}^{T_i} f[y_{it} | (\beta_s + w_i), X_{it}] h(w_i | \Sigma_s) dw_i \quad (5)$$

The class probabilities are parameterized using a multinomial logit formulation to impose the adding up and positivity restrictions on $\pi_s(\theta)$. Thus,

$$\pi_s(\theta) = \frac{\exp(\theta_s)}{\sum_{s=1}^S \exp(\theta_s)}, s = 1, \dots, S; \theta_S = 0 \quad (6)$$

Hence, in the LCRPLM, an individual i chooses among J alternatives in a choice situation t with conditional probabilities of:

$$f[y_{it} | (\beta_s + w_i), X_{it}] = \frac{\exp[\sum_{j=1}^J y_{itj}(\beta_s + w_i)'x_{itj}]}{\sum_{j=1}^J \exp(\sum_{j=1}^J y_{itj}(\beta_s + w_i)'x_{itj})}, \quad s = 1, \dots, S \quad (7)$$

with $y_{itj} = 1$ for the j corresponding to the alternative chosen and 0 for all others, and x_{itj} is the vector of attributes of alternative j for individual i in choice situation t . As in our empirical approach, class membership has been estimated based on irrigators' preferences only (thus not including individual-specific characteristics). Then the contribution of individual i to the simulated log likelihood can be written as:

$$f^S(y_i | X_i, \beta_s, \theta, \Sigma_s) = \sum_{s=1}^S \pi_{is}(\theta) \cdot R^{-1} \sum_{r=1}^R \prod_{t=1}^T f[y_{it} | (\beta_s + w_{ir}), X_{it}] \quad (8)$$

with w_{ir} being the r th of R random draws on the random vector w_i . For an overview of the specification of the LCRPLM, we suggest Greene y Hensher (2013).

In the LCRPLM used here, the attributes μ , σ^2 and $Cost$ are treated as linear variables, assuming a normal distribution for the former two and a triangular distribution for the latter. We account for an individual-specific status quo for the attributes μ and σ^2 , using the information collected through the questionnaire.

The selection of the LCRPLM used in the analysis was made based on model parsimony, significance level of the parameters and interpretability with respect to policy relevance (Scarpa y Thiene, 2005). Serial non-participants (i.e., respondents always choosing the status quo option) who did not state protest reasons, and who are thus clearly stating zero WTP for improvements in water supply reliability, were excluded from the latent class analysis, but were considered in a subsequent bivariate analysis used to investigate factors influencing farmers' preferences. Within the remaining sample of non-zero WTP respondents, the final selection of a 2-class solution yielded the best results according to these criteria.

Marginal WTP was estimated by calculating the ratio of the coefficient of the non-monetary attribute (μ or σ^2) to the negative of the coefficient of the monetary attribute ($Cost$) (Hensher et al., 2005). Total WTP for scenarios ($I1$, $I2$, and $I3$) of improvement in water supply reliability was estimated following Hanemann (1984). For estimates of both marginal and total WTP, we applied the parametric bootstrapping approach by Krinsky and Robb (1986).

In addition, to further explore sources of heterogeneity, bivariate analyses using Jonckheere-Terpstra non-parametric test and Chi-squared test were used to investigate statistical differences between the three classes for numerical and categorical variables respectively.

4 Results and discussion

4.1 Latent class model

In this section, the results of the latent class random parameter logit model (LCRPLM) are presented and discussed. From the valid questionnaires (196), 88 irrigators (44.9%) systematically chose the 'no change' or status quo alternative. We can then assume that this group of irrigators have zero WTP for improvements in water supply reliability, forming the *Class 0*.

Table 3 displays the LCRPLM results of the remaining observations (i.e., 108 farmers resulting from censoring zero bidders). The model shows a high goodness-of-fit (Pseudo $R^2=0.304$), and all the parameters of the utility function are significantly different from zero. The model clearly distinguishes two different classes of irrigators. *Class 1* has a membership probability of 50.05% (28.6% of all irrigators interviewed). *Class 1* preferences are determined by the three attributes considered but, especially, by the attribute *Cost* which unlike the non-monetary attribute parameters shows a statistical significance level of 1%. *Class 2* has a corresponding membership probability of 49.96% (26.5% of total irrigators). All of the three attribute parameters (μ , σ^2 and *Cost*) are highly significant.

Table 3 Latent class random parameter logit model (LCRPLM)

	<i>Class 1</i>		<i>Class 2</i>	
	<i>Coef.</i>	<i>SE</i>	<i>Coef.</i>	<i>SE</i>
<i>Mean parameters</i>				
μ (Increase in 100 m ³ /ha/year)	0.040*	0.024	0.079***	0.024
σ^2 (Decrease in 10.000 (m ³ /ha/year) ²)	0.003*	0.002	0.008***	0.004
<i>Cost</i> (Per €/ha)	-0.113***	0.021	-0.014***	0.003
ASCsq	-1.215***	0.300	-1.193***	0.399
<i>Standard deviations</i>				
μ	0.000	0.011	0.000	0.010
σ^2	0.001	0.002	0.000	0.003
<i>Cost</i>	0.000	0.017	0.007*	0.004
Class probability	0.5005***	0.0755	0.4996***	0.0755
Log-likelihood (LL)	-495.50			
McFadden Pseudo R ²	0.304			
AIC/N	1.576			
Observations (individuals)	648 (108)			

Source: Own elaboration.

*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

As expected, the mean parameter μ , defined as ‘an increase in 100 m³/ha/year’, is a significant determinant of choice behavior among irrigators in *Class 1* and *Class 2*. Its positive sign indicates that a greater mean of the PDF of water supply is associated with a utility gain to farmers. The σ^2 parameter, defined in terms of ‘a decrease in 10,000 (m³/ha/year)²’, also has the expected positive sign, implying that farmers experience an increase in utility if the variance of the PDF of water supply is reduced.

The *Cost* parameter has a negative and highly significant effect on utility of irrigators in *Class 1* and *Class 2*, revealing that, as expected, irrigators are very sensitive to changes in irrigation water fees associated with alternatives of improvements. In particular, observing the *Cost* coefficients for both classes, and ignoring potential differences in scale between classes, respondents in *Class 1* appear to be much more sensitive than those belonging to *Class 2*.

The constant, ASCsq, is significantly different from zero and negative for both classes, thus showing a tendency to choose the alternatives of improvements of water supply reliability for reasons unrelated to the attributes. This finding is in line with previous studies (Mesa-Jurado et al., 2012, Alcón et al., 2014), which also find strong systematic preference for alternatives that improve water supply reliability among irrigators.

Table 4 depicts marginal WTP for the attributes μ and σ^2 (all of the estimates are significantly different from zero).

Table 4 Mean marginal willingness to pay (WTP) for each class (in brackets, confidence intervals at 5% level) (€/ha/year)^a

Attribute	Class 1	Class 2
μ (Increase in 100 m ³ /ha/year)	0.35* (-0.07 – 0.72)	5.81*** (2.50 – 9.80)
σ^2 (Decrease in 10.000 (m ³ /ha/year) ²)	0.03** (0.00 – 0.07)	0.61** (0.08 – 1.18)

Source: Own elaboration.

*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

^a Estimates are obtained using the bootstrap method (with 5000 replications) proposed by Krinsky y Robb (1986).

Table 5 shows the estimates of total WTP of *Class 1* and *Class 2* for the three selected scenarios of improvement (*I1*, *I2* and *I3*) of water supply reliability. As can be seen, all the estimates of total WTP are statistically significant at the 1% level. If we compare these results with the total current irrigation water expenses (€255.5/ha/year), it can be inferred that *Class 1*'s and *Class 2*'s irrigators are willing to increase their current fees by 5.5-7.5% and 53.5-88.4%, respectively, for improvements in water supply reliability. These results reveal the different preferences of both classes of irrigators toward improving water supply reliability.

Table 5 Mean total willingness to pay (WTP) for each class for scenarios of improvement of the water supply reliability (in brackets, confidence intervals at 5% level) (€/ha/year)^a

Scenarios	Class 1	Class 2
<i>I1</i> : $\mu=3,179$; $\sigma^2=417,316$ (annual gap reduced in 25%)	14.0*** (10.3 – 19.0)	136.6*** (84.0 – 221.4)
<i>I2</i> : $\mu=3,786$; $\sigma^2=185,761$ (annual gap reduced in 50%)	16.6*** (12.7 – 21.5)	182.4*** (126.7 – 274.0)
<i>I3</i> : $\mu=4,393$; $\sigma^2=46,225$ (annual gap reduced in 75%)	19.2*** (13.6 – 25.3)	225.8*** (158.6 – 337.0)

Source: Own elaboration.

*** denotes significance at the 1% level.

^a Estimates are obtained using the bootstrap method (with 5000 replications) proposed by Krinsky y Robb (1986).

Overall, the results indicate that the majority of irrigators enjoy increases in their individual utility by shifting from the current situation to the different scenarios of improvement of water supply reliability. These results reveal great differences in preferences among irrigators for improving water supply reliability. Some respondents are willing to pay nothing (*Class 0*), others have low WTP (*Class 1*), and the rest has high WTP (*Class 2*). It can be presumed that not only irrigators with zero WTP, but also most of *Class 1*'s irrigators rejected the construction of the abovementioned ponds because of the low magnitude of their mean WTP that is smaller than the estimated annual cost of the three ponds (€38/ha). This heterogeneity of irrigators' preferences toward water supply reliability is of great interest to policy-makers for the design of demand-side water supply instruments (water markets, water banks, insurance schemes, etc.).

4.2 Bivariate analysis

Table 6 shows the main results from the bivariate analysis of explanatory variables (sociodemographic, structural and opinions/attitudes). As can be observed, the results show that the three classes are homogeneous but different from each other, with a variety of variables explaining the different intensity of preferences toward water supply reliability.

Table 6 Description of the classes. Average values of numerical and categorical (1=Yes in %) variables

Variable	Class 0	Class 1	Class 2	Coef.	p-value
Percentage of olive groves area over total farm irrigated area (%)	35.2	22.5	25.6	-1.722	0.085*
Average water needs (m ³ /ha/year)	2,772	2,998	3,192	1.881	0.060*
The farmer knows the water allotment received on average in the last 5 years (1=Yes; 0=No)	29.5	30.4	48.1	5.605	0.061*
Perception of level of water consumption with respect to other farmers with the same crops (from 1: Well above average; to 5: Well below average)	3.4	3.3	2.9	-3.177	0.001***
System to decide how much and when to irrigate: As suggested by the IC staff (1=Yes; 0=No)	11.4	25.0	26.9	6.643	0.036*
Farmer's age (years)	58.8	54.7	53.7	-2.340	0.019**

Source: Own elaboration.

*, ** and *** denote significance at the 10%, 5%, and 1% levels, respectively.

The main differences between classes are found for farm characteristics related to irrigation water dependency and, to a lesser extent, socio-demographic variables, wider farm management and knowledge about water allotments. Regarding variables closely related to *water dependency*, the three classes are significantly different from each other for 'Percentage of olive groves area over total farm irrigated area' and 'Average water needs'. Irrigators with zero WTP (*Class 0*) have a higher percentage of their farm area used for olive groves (35.2%) compared to farmers in *Class 1* and *Class 2* (22.5% and 25.6%, respectively). Olive groves are a permanent crop with low water needs (around 2,000 m³/ha/year) that is very resilient to drought and traditionally farmed under rainfed conditions, compared to other common crops grown in Genil-Cabra IC (e.g., vegetables and cotton). Similarly, WTP across classes seems to be positively related to irrigators' 'Average water needs'. *Class 0*, *Class 1*, and *Class 2* farmers are estimated to have 2,772 m³/ha/year, 2,998 m³/ha/year, and 3,192 m³/ha/year of average water needs, respectively. It is unsurprising that *Class 0*'s water needs are only slightly above the mean current water supplied in the IC (2,572 m³/ha/year), while average water needs for *Class 1* and *Class 2* are well above that figure. In sum, these two variables reflect different levels of dependency with respect to irrigation water use (i.e., risk exposure to water shortages), and provide some validity to results by showing that higher levels of dependency (risk exposure) are associated with higher the WTP for improving water supply reliability.

With regard to *socio-demographic variables*, we find significant differences for 'Farmer's age', with *Class 0*'s irrigators being older than *Class 1*'s and *Class 2*'s farmers (58.8 years compared to 54.7 and 53.7 years, respectively). This result is consistent with Mesa-Jurado et al. (2012) and Alcón et al. (2014), who showed that older irrigators tend to be less likely to pay for improvements in water supply reliability.

With regard to other *farm characteristics and management variables*, we find that *Class 0*'s irrigators follow technical suggestions from the IC staff to decide how much and when to irrigate less compared to *Class 1*'s and *Class 2*'s irrigators. This suggests that *Class 0*'s irrigators base their farm decision-making less on technical criteria compared to the other two classes.

Concerning *farmers' opinions and knowledge*, the three classes are significantly different with respect to 'Perception of level of water consumption for the main crop with respect to other farmers with the same crop'. The higher perceived water consumption, the higher is WTP for improving water supply reliability. Those farmers with a higher than average perceived water consumption stated that this has more to do with each farm's soil quality (mostly, shallower and less fertile soils usually requires higher water consumption) rather than to an irresponsible water use issue. In addition, the variable 'The farmer knows the water allotment received on average in the last 5 years' is also significant, implying that those who are willing to pay more to improve water supply reliability (i.e., *Class 2*) know the water allotment received to a greater extent compared to those who are less willing to pay for it.

5 Conclusions

Under uncertainty, optimal levels of irrigation water use and agricultural production are typically lower than under certainty conditions. This is particularly the case in semi-arid regions where irrigators' farm decision-making strongly relies on water supply reliability, very often amid acute resource scarcity. Under these circumstances, information on irrigators' preferences with regard to water supply reliability is very useful to design policy instruments aiming at improving the efficiency of irrigation water use under uncertainty conditions. This fact justifies why the present research examines irrigators' WTP for improvements in water supply reliability. Compared to previous investigations into this topic that treated irrigation water supply as a deterministic variable, this study characterizes it as a stochastic variable, with its own distributional function. Thus, we add to that literature by providing more reliable estimates of irrigators' WTP for improvements in water reliability based on changes in the probability density function of water supply using the mean-variance approach and the choice experiment.

The results show that the majority of irrigators obtain utility gains by shifting from the current situation to different scenarios of improvement of water supply reliability characterized by changes in the probability density function. Three different types of irrigators are distinguished according to their WTP: i) those who are not willing to pay nothing (*Class 0*); ii) those with low WTP (*Class 1*); and iii) and those with high WTP (*Class 2*). *Class 0*'s and *Class 1*'s irrigators exhibit a mean WTP for water supply reliability that is lower than the annual cost of a structural measure (three irrigation ponds) that had been proposed to improve current situation in the case study area. This may explain why the measure's implementation was ultimately rejected. Therefore, the different preferences of the three classes of irrigators toward improving water supply reliability suggest the convenience of more targeted demand-side instruments for improving water management under supply uncertainty conditions.

In addition, significant differences between classes are analyzed to identify factors influencing irrigators' preferences toward water supply reliability. The results suggest that farm characteristics related to irrigation water dependency (i.e., water availability risk exposure) significantly determine WTP for improving water supply reliability,

showing a positive relationship (i.e. the higher the level of dependency –risk exposure–, the higher WTP). Moreover, the results show that sociodemographic variables, farm management (besides water-related), and knowledge also influence WTP for such improvements, although to a lesser extent than irrigation water dependency.

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