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

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Asbtract

In irrigated agricultural systems, a major source of uncertainty 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 (47.8%) while others have a relatively low (28.0%) or high (24.2%) 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 can be used to assist the design of more efficient policy instruments to improve water supply reliability in Mediterranean and semi-arid climate regions.

***Keywords**:* Choice experiment, irrigation water availability, mean-variance approach, preference heterogeneity.

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1. Introduction

Farmers worldwide are faced with a variety of risks that originate from various sources. Within these, production risks (mainly due to weather events affecting crop yields) and market risks (mainly due to changes in agricultural prices) are considered to be among the most important (OECD, 2011). Although price variability is found to be higher than yield variability in most countries, this is not the case in Mediterranean and semi-arid climate regions, which are subjected to significant variability of weather conditions (irregular precipitation and frequency of extreme events) (Antón and Kimura, 2011). This explains why Mediterranean agriculture is particularly vulnerable to the risk of drought, a source of uncertainty that is becoming increasingly relevant because of climate change is projected to involve an increase in the frequency and intensity of the drought events in these regions (IPCC, 2014; EC, 2017). All of these facts help to explain why irrigators in these regions are deeply concerned about uncertainty over water supply, which significantly affects economic decision-making in irrigated agriculture (Palinkas and Székely, 2008). In fact, in Mediterranean and semi-arid climate regions irrigation water availability is one of the main sources 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.

According to the neoclassical production theory, under certainty conditions an efficient farmer uses inputs (e.g., irrigation water) up to a level at which the marginal revenue product equals marginal costs. But under uncertainty regarding input availability and risk aversion, optimal levels of input use and output produced are lower than those expected under certainty conditions, as shown by Beare et al. (1998) for the case of irrigation water. In addition, it is worth mentioning that uncertainty over water supply impacts on farmers' choices of crop portfolio. Farmers may prefer crops whose production requires less agricultural capital accumulation despite being less profitable (Lavee, 2010), and be dissuaded from making long-term investments that raise productivity (Marques et al., 2005). Thus, considering that most farmers are risk averse, under uncertainty regarding irrigation water availability, irrigators' decision-making (i.e., optimal input level use from a private point of view) cannot be considered efficient from a social welfare perspective (agricultural production and wealth generation is lower than under more certain irrigation water availability).

All these facts evidence that there is a responsibility for both farmers and governments to address the risk related to irrigation water availability (OECD, 2016; EC, 2017). While farmers should be expected to incorporate the risk of shortages of irrigation water into their own risk management strategies without any public incentive, there is a role for public policy to encourage farmers to adopt drought risk management instruments (e.g., designing security-differentiated water rights or subsidizing agricultural insurances) and to support irrigators in case they suffer catastrophic losses (e.g., ad-hoc payments or fiscal measures), with the ultimate objective of increasing economic efficiency and social welfare, along with stabilizing irrigators' incomes (Rigby et al., 2010).

Furthermore, concerns over water supply reliability in agriculture are growing because of the expected impact of climate change. According to IPCC (2014), projections for Mediterranean and semi-arid climate regions continuously indicate a decrease in precipitation, run-off and water availability, while the progressive temperature rise will increase irrigation water needs due to higher evapotranspiration of crops, resulting in greater demand for irrigation water. Moreover, climate change predictions for these regions also point out that drought periods are expected to be more frequent and intense. All this will jeopardize irrigation water supply reliability, encouraging irrigators and policy-makers to develop more proactive adaptation measures (Varela-Ortega et al., 2016).

Traditionally, solutions for securing water supply have focused on the supply side, mainly through the construction of large-scale infrastructures such as reservoirs, aqueducts and pipelines to capture, store and transfer water resources to satisfy human needs (mainly for urban and agricultural uses). Thus, these supply-side policies aim at satisfying increasing water demands by means of increasing the resource availability. However, supply-side policies often do not represent a viable option anymore in Mediterranean and semi-arid climate 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 (disproportionately costly investment requirements) and environmental (maintenance of natural flows to conserve water related ecosystems) 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 and academics increasingly explore demand-side instruments. These instruments aim at managing the current available resources to optimize water use efficiency and reduce water users’ (including irrigators) exposure to water availability risk. They include modernization of irrigation systems (Berbel et al., 2015), spot water markets (Calatrava and Garrido, 2005b; Debaere et al., 2014), drought water banks (Montilla-López et al., 2018), option contracts (Rey et al., 2016) and drought insurance schemes (Pérez-Blanco and Gómez, 2014).

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). Rigby et al. (2010) estimated the economic value of water to irrigation producers in the Segura Basin (Spain) using a choice experiment and explored if irrigators were willing to pay a premium for less uncertain water supplies. They found that farmers were strongly risk averse in their preferences and agreed to pay higher water fees for increasing the probability of additional water amounts. Mesa-Jurado et al. (2012) used the contingent valuation method to analyze olive grove irrigators in a river sub-basin in southern Spain, finding that 71% of irrigators were willing to pay for improved water supply reliability, and showing that greater improvement was associated with higher WTP. Bell et al. (2014) used a choice experiment to study Pakistani farmers' WTP for improved water supply reliability, finding that irrigators were typically willing to pay more than the current average water fees for an improvement in reliability. They also found that farmers' WTP relates to the current level of water supply reliability, with WTP being higher for farmers who already have a high level of reliability. Finally, Alcón et al. (2014) analyzed farmers' WTP for improved water supply reliability under different policy options using choice experiments. These authors also found that farmers were willing to pay extra money for improvements in water supply reliability, and that their WTP varied depending on the policy instruments used to secure such improvements.

All of these studies provide useful insights into the issue of water supply reliability, revealing interesting results related to farmers' preferences to improve water supply for irrigation. However, to a large extent, the valuation scenarios described secured or riskless amounts of water supply as alternatives to the current situation which, in our opinion, lacks realism. In these papers, the amount of water available for irrigation was considered as a deterministic variable (secured and completely reliable water supply amounts), instead of as a stochastic one with its own probability density function, which is arguably much closer to real decision-making with regard to improvements in water reliability. Taking this into account, the main objective of this paper is to provide first evidence on farmers' preferences toward irrigation water supply reliability, defined as shifts in the probability density function of water supply. Specifically, this paper adds to existing literature by valuing changes in irrigators' utility associated with changes in both mean and variance of water allotments. To our knowledge, this has not been done previously.

Toward this end, this paper examines irrigators' WTP for improvements in water supply reliability (joint increase in the mean of water allotments and decrease in their variance) 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 model (LCM) 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

2.1. Water management in Spain: Water concessions and water allotments

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 in Spain for a maximum amount of water to be used annually (water concession) during a fixed period of time (75 years, generally) and for uses specifically designated in the legal document fixing features of these rights. However, based on a `proportional rights' system, Spanish public basin agencies have legal capacity to impose restrictions on the volume of water to be actually used each year (water allotments) depending on the resource availability (i.e., water stored in reservoirs). Indeed, in water scarce regions with closed basins, as in southern and eastern Spain, annual water allotments only reach water concessions under wet hydrologic conditions. Consequently, irrigators in these regions generally face a considerable level of uncertainty about the actual availability of irrigation water (Calatrava and Garrido, 2005a).

For irrigation purposes, concessions are usually granted collectively to all irrigators operating within the same irrigation district, being the water annual allotments managed as a common property resource through water user associations called irrigators' communities (*comunidades de regantes* or simply ICs). Under this institutional setting, a proportional appropriation rule is applied, since ICs deliver the water available among the irrigators on an area-based criterion; that is, farmers obtain the same amount of water per irrigated hectare that is fixed annually, although they can use the whole volume allotted with different intensities within their own farms. Thus, within the same irrigation district all irrigators usually share the same risk of water shortage.

2.2. Case study: Santaella Irrigators' Community in the Genil-Cabra irrigation district

The Santaella IC in the Genil-Cabra irrigation district (from now on referred simply as Santaella IC), located in the Guadalquivir River Basin (GRB, southern Spain), has been selected as case study. This irrigation district has been primarily selected for the empirical analysis due to representativeness, since it is an irrigated system sharing most of its features with many other irrigated districts within the GRB. Moreover, it is worth mentioning that this choice was also supported by empirical reasons, taking into account the availability of data (i.e., Lorite et al., 2007; Lorite et al., 2013).

Santaella IC is a large irrigators' community (15,500 hectares) using surface water resources delivered by the GRB agency. As many ICs within the basin, the Santaella IC was established at the end of the 20th Century, currently operating with modern and efficient irrigation technologies, with sprinkler and drip irrigation systems being most widely used (Gómez-Limón et al., 2013). 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, and variable costs, covering energy consumed for pumping, borne by the IC due to the provision of water services. These costs are charged to irrigators separately through a binomial bill including two components based on area (fixed costs imputation) and volumetric (variable costs imputation) criteria. Main descriptive characteristics of Santaella IC are shown in Table 1.

Table 1

Descriptive characteristics of Santaella IC.

Characteristics	Santaella IC
Operations starting date	1989
Irrigated area (ha)	15,500
Number of owners of irrigated land[a]	1,563
Average size of irrigated farm (ha)[a]	25.0
Main crops	Olives (45%), sunflower (14%), vegetables (12%), wheat (11%) and cotton (11%)
Origin of water resources	Surface (100%)
Water concession (m^3/ha/year)	5,000
Average annual water allotment (m^3/ha/year)	2,572
Irrigation system	Sprinkler (50%) and drip irrigation (50%)
Area water price (€/ha/year)	147.50
Volumetric water price (€/m^3)	0.042

Source: Data provided by the IC.

[a] Owners of irrigated land in this IC have, on average, 9.9 hectares. However, due to land leasing and other management arrangements, irrigated farms (management unit) have, on average, 25.0 hectares.

As for most of the ICs in the GRB, the Santaella IC does not commonly receive the water allotments of the legal concession of 5,000 m^3/ha/year for which it is entitled. In contrast, water allotments are generally lower, generating a considerable supply gap in most of the years, as can be observed in Fig. 1. In fact, the average water use in the past 20 irrigation seasons has been of 2,572 m^3/ha/year (51.4% of water concession) with considerable variation demonstrating relatively low levels of water supply reliability. Fig. 2 displays the histogram of annual water allotments. To improve water supply availability and reliability, the board of the IC proposed the construction of three irrigation ponds to enlarge water storing capacity, which were projected to cost €27m (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.

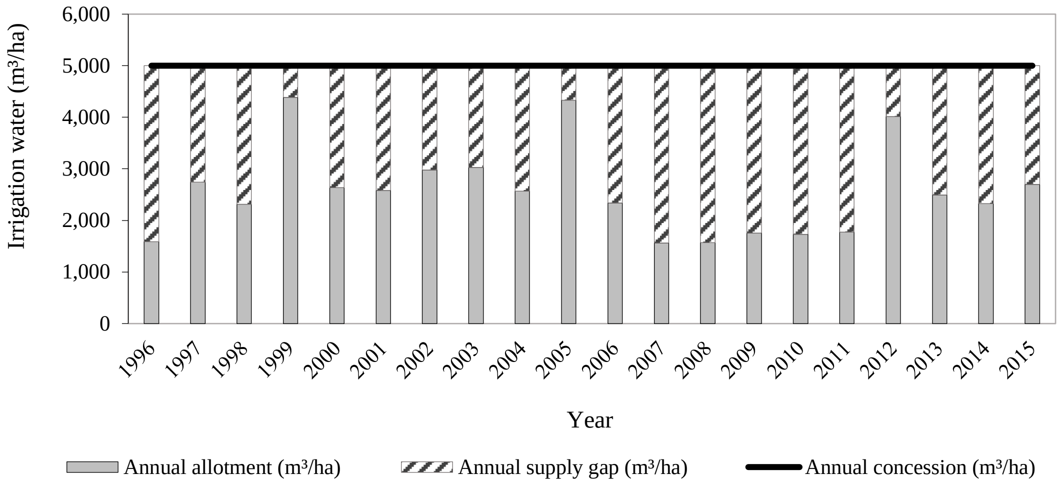


Fig. 1. Water allotments and supply gaps in Santaella IC.

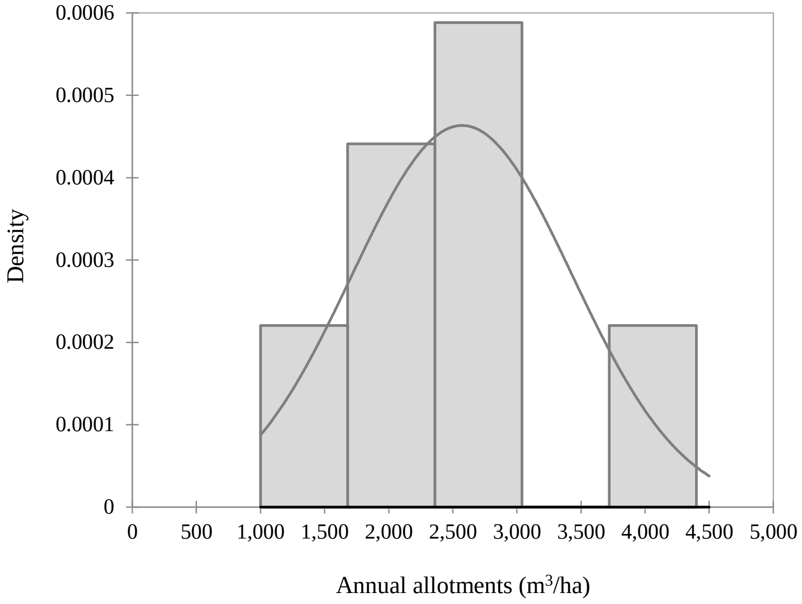
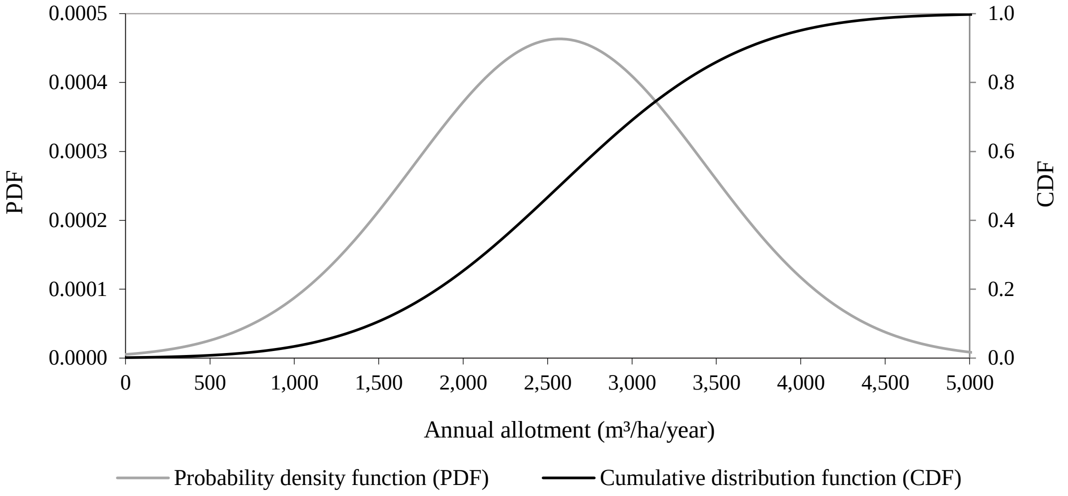


Fig. 2. Histogram of annual water allotments in Santaella IC.

Water allotment can be considered as a stochastic variable with its own PDF and CDF. From the series of water allotments in Santaella IC in the period from 1996 to 2015, and using the software *Easyfit 5.6* (Mathwave Technologies), we have fitted data to several possible distribution functions. The normal distribution function resulted as one of the most accurate distribution functions to represent variability in water supply, according to the Anderson-Darling (A-D) statistical test (the null hypothesis of data following normal distributions was not rejected at 1% significance level). Fig. 3 shows the normal PDF and CDF for the data of water allotments in Santaella 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.



μ=2,572 m³/ha/year σ^2=741,321 (m³/ha/year)²

Fig. 3. Normal PDF and normal CDF in Santaella IC (current scenario).

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 (Santaella IC) to characterize the current scenario, as shown in Fig. 1. 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 also using *Easyfit 5.6*. In all cases, data were consistent with normal distribution functions as proved with an A-D statistical test. For illustrative purposes, the resulting normal CDFs are shown in Fig. 4.

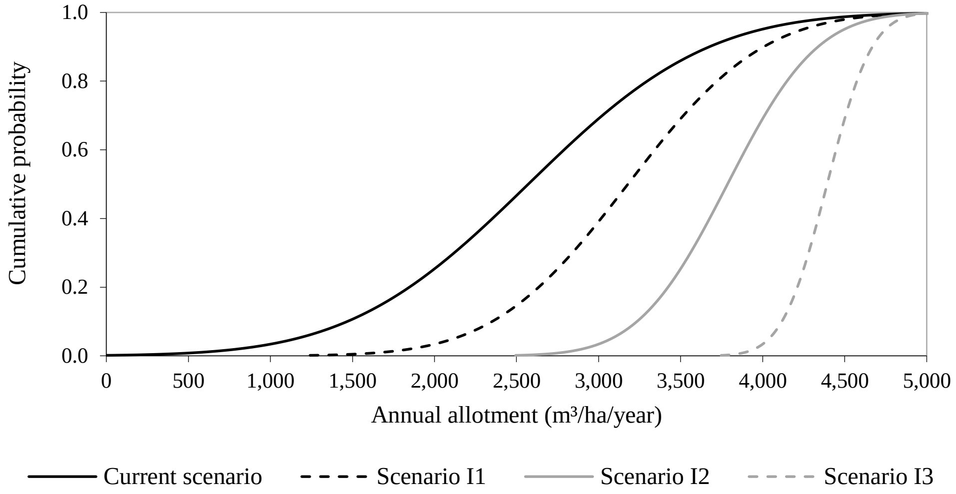


Fig. 4. Normal CDFs in Santaella IC in current scenario and in the improved scenarios (*I1*, *I2*, *I3*).

Table 2 shows μ and σ^2 parameters of the normal distribution functions fitted for each scenario. Other useful descriptive statistics, such as 5th, 25th and 50th percentiles, are also provided.

Table 2

Estimated statistics of the probability density functions for the different water reliability scenarios in Santaella IC (m^3/ha/year).

Parameters	Current scenario (Status Quo: SQ)	Improvement scenarios		
		Scenario *I1* (gap -25%)	Scenario *I2* (gap -50%)	Scenario *I3* (gap -75%)
μ	2,572	3,179	3,786	4,393
σ^2	741,321	417,316	185,761	46,225
P05	1,155	2,117	3,078	4,039
P25	1,991	2,743	3,495	4,248
P50	2,572	3,179	3,786	4,393

Source: Own elaboration using irrigators' community data.

3.2. Mean-variance approach

The mean-variance approach (Levy and Markowitz, 1979) was proposed for financial portfolio selection in order to help investors to maximize the financial asset's return while minimizing its risk. In fact, this approach has been widely proved to be consistent with expected utility theory (Markowitz, 2014), thus providing a sound theoretical framework for analyzing the decision-making under risk beyond financial analysis, becoming one of the most widespread approaches in applied economics to model decision-making under risk (Hardaker et al., 2004). 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 (Nauges et al., 2016).

The mean-variance analysis relies on two basic requirements for this approach to be precise when modeling decision-making: (i) the risky outcome (variable 'water supply reliability' in our case study) is normally distributed, and (ii) the decision-maker's (irrigators in our case study) utility function is quadratic. The first assumption has been already verified in Section 2.2, but no evidence is available on whether the second one is actually met. However, as pointed out by Hardaker et al. (2004, p. 143), the mean-variance approach provides a sound theoretical framework for analyzing decision-making under risk, even if both requirements are not fully met. This justifies the analysis of irrigators' preferences toward changes in variable 'water supply reliability' through changes in the parameters of the PDF of water supply (mean and variance).

The mean-variance approach has been scarcely incorporated in choice experiments with applications mainly in transport research related to estimating WTP for improvements in travel time reliability (Li et al., 2010). In agricultural and environmental domains, only few studies follow this methodological framework, despite the stochastic features of many of the attributes valued in application within these fields. An example that is worth mentioning is Gallardo et al. (2009), who used the mean-variance approach in a choice experiment to determine millers' preferences for the level and variability of winter wheat attributes. 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.

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. This method has been extensively used to analyze farmers' preferences (see Villanueva et al., 2017, for a review), with some works focusing on water supply reliability (namely, Rigby et al., 2010; Alcón et al., 2014; Bell et al., 2014).

The choice experiment implemented in the case study analyzed here considered three attributes. Table 3 shows the attributes and levels used for this empirical study.

Table 3

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)	$\mu_{SQ} = 2{,}572; \mu_{I1} = 3{,}179; \mu_{I2} = 3{,}786; \mu_{I3} = 4{,}393$ (m^3/ha/year) (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)	$\sigma^2{}_{SQ} = 741{,}321$; $\sigma^2{}_{I1} = 417{,}316$; $\sigma^2{}_{I2} = 185{,}761$; $\sigma^2{}_{I3} = 46{,}225$ ((m^3/ha/year)^2) (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

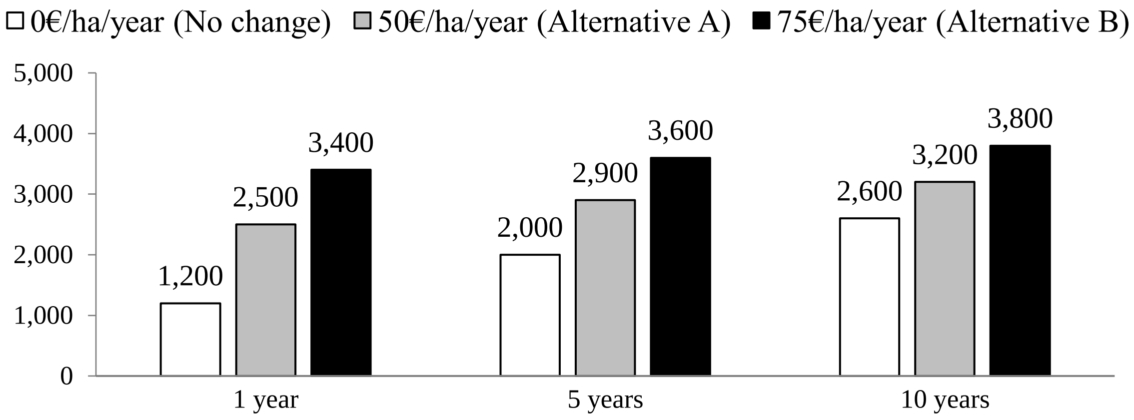
Source: Own elaboration.

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. For the attribute related to μ (location parameter of the normal PDF of water supply reliability), the levels are μ_{SQ}, μ_{I1}, μ_{I2} and μ_{I3}. The levels of the attribute σ^2 (scale parameter of the normal PDF) are $\sigma^2{}_{SQ}$, $\sigma^2{}_{I1}$, $\sigma^2{}_{I2}$ and $\sigma^2{}_{I3}$. The values of these levels for the irrigation district analyzed are shown in Table 2 and Table 3.

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 the following six levels: 2%, 5%, 10%, 20%, 30% and 50%. These levels correspond to the following absolute terms (after rounding): €5, €10, €25, €50, €75 and €125 per hectare and year. These levels where initially chosen considering both value estimates previously obtained in the literature and local stakeholders' opinion. Moreover, these levels were checked during the pre-test in order to confirm they cover the whole range of respondents' WTP in the case study area.

Because the parameterization of the normal PDF (mainly the attribute σ^2) is abstract and cannot be directly understood by farmers, the combinations of the levels of the attributes μ and σ^2 that characterize changes in the PDF of water supply were shown through three points of the CDF corresponding to 5th, 25th and 50th percentiles. Presented in this way, farmers were able to understand the different degree of water supply reliability reflected by each combination of attribute levels. For example, in an alternative including the combination of the levels μ_{I1} and $\sigma^2{}_{I2}$ (Alternative A in the example of choice card presented in Fig. 5), farmers were shown the following information: in 1 year out of 20 years they would receive less than 2,500 m^3/ha/year; in 5 years out of 20 years they would receive less than 2,900 m^3/ha/year; and in 10 years out of 20 years they would receive less than 3,200 m^3/ha/year (all figures have been rounded to 100s). As for the scenarios, the information regarding 5th, 25th and 50th percentiles were elicited as a result of representing normal PDF in the *Easyfit 5.6* software using the different combinations of the levels of the two attributes.

Water supply reliability: Out of 20 years… (in m^3/ha/year)



I would choose (please tick one):

☐ No change (SQ) ▨ Alternative A ■ Alternative B

Alternatives considered: *No change*=(μ_{SQ}, $\sigma^2{}_{SQ}$); *Alternative A*=(μ_{I1}, $\sigma^2{}_{I2}$); *Alternative B*=(μ_{I2}, $\sigma^2{}_{I3}$).

Fig. 5. Example of choice card.

3.4. Experimental design and data gathering

As any other choice experiment application, the use of an experimental design is needed. It consists of combinations of attribute levels used to construct the alternatives included in the choice tasks. Within alternative options to generate experimental designs, efficient designs (i.e. those pursuing the minimum predicted standard errors of the parameter estimates) are widely used and highly recommended, especially due to the lower sample of combinations needed to elicit statistically robust results (Bliemer and Rose, 2011). Therefore, in the current research, a two-stage sequential efficient design was geared toward the minimization of the expected D_b-error (Scarpa and Rose, 2008)[2], with the final design including 24 choice tasks distributed to 4 blocks. Each farmer hence faced one block comprising 6 choice tasks.

A representative sample (n=205) of irrigators operating in Santaella IC (N=1,563) was drawn. Individuals were randomly selected accounting for farm size quotas. Questionnaires were completed by face to face interviews, conducted from October 2016 to December 2016. Farm and farmer characteristics of the sample are reported in Tables A.1 and A.2 in Appendix A.

The chi-square tests for equality of distributions do not reject the null hypothesis of equality of sample and population proportions regarding key socioeconomic and structural variables (age, gender, farms size and crop distribution), supporting the representativeness of the sample.

Before administering the DCE questionnaire to each participant, the interviewer explained the objectives of the research and provided a careful explanation on the meaning of the

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[2] The optimization is computed by simulation on the basis of prior distributional assumptions of utility parameters. In the first stage, for the pre-test, an efficient design (D_b-error=0.084) with priors assumed to follow triangular distributions with a wide spread was used. In the second stage, the estimates of a multinomial logit model (MNL) calculated from the 40 interviews gathered during the pre-test were used to set priors –assumed to be normally distributed– in order to generate the D_b optimal efficient design (D_b-error=0.049).

attributes and their levels using illustrative materials (available to readers upon request). At the end of each survey, the interviewer assessed farmer’s comprehension of the DCE exercise implemented using a 5-point Likert scale variable. Of the 205 irrigators interviewed, four were assessed to have a low level of comprehension and five were considered to be protest responses. All these nine interviewees were omitted from the sample, hence reducing the total number of valid questionnaires used in the analysis to 196.

3.5. Econometric specification

A latent class model (LCM) was used to model farmers’ choices regarding irrigation water supply. The LCM model is suitable for investigating respondents’ preference heterogeneity if a considerable richness in the structure of preferences is present that supports the hypothesis that there are several discrete latent classes, which would otherwise be unobservable (Greene and Hensher, 2003). Unlike continuous mixed models (such as random parameter logit models), LCM allows the grouping of individuals in accordance to their preferences, which is very useful when preference heterogeneity is analyzed, especially for eliciting policy implications (Hess et al., 2011).

In LCM it is assumed that individuals are implicitly sorted into a set of s classes, associated with a discrete parameter variation. The specific class of each individual is unknown to the analyst, thus the LCM approach is based on a class membership probability equation, which has a logit formulation (assuming that the error components are identically and independently distributed following a Gumbel distribution). Preference heterogeneity is captured by simultaneously assigning individuals to behavioral groups or latent classes while estimating a choice model. Formally, in the LCM, the utility (*U*) of alternative $j \in$ J to individual *n* (in a choice situation *t*) who belongs to class *s*, can be written as:

$$U_{jnt|s} = \beta_s X_{jnt} + \varepsilon_{jnt} \tag{1}$$

where X_{jnt} is a vector of attributes associated with alternative j and individual n, β_s is a class specific parameter vector associated with the vector of explanatory choice attributes X_{jn} and ε_{jn} is the unobserved heterogeneity (the scale parameter is normalized to 1 and omitted). Within the class, choice probabilities are assumed to be generated by the multinomial logit model. The probability (P) of an individual n, who makes a sequence of choices (y_1, y_2,… y_T) among a particular set of alternatives J, to belong to s is given by the following common formulation:

$$P_n([\mathrm{y}_1, \mathrm{y}_2, \dots . \mathrm{y}_\mathrm{T}]) = \sum_{s=1}^{S} \left[\frac{\exp(\alpha_s Z_n)}{\sum_{s=1}^{S} \exp(\alpha_s Z_n)}\right] \left[\prod_{t}^{T} \frac{\exp(\beta_s X_{jnt})}{\sum_{j=1}^{J} \exp(\beta_s X_{jnt})}\right] \quad s = 1, \dots, S \qquad (2)$$

where the first expression in brackets is the probability of observing the individual in class s according to a set of individual-specific characteristics (the Z_n variables and their parameters α_s), with the remaining coefficients explained above. An overview of the specification of the LCM can be found in Hess et al. (2011).

In our empirical approach, the attributes μ and σ^2 are treated as dummy variables, including two levels for each. For the first attribute, the dummy variable $\mu 1$ represents a moderate improvement in the mean water supplied (corresponding to an average of 3,179 m^3/ha/year, i.e., the μ_{I1} level), while the dummy variable $\mu 2$ represents a significant improvement in the mean water supplied (corresponding to an average equal to or higher than 3,786 m^3/ha/year, i.e., the μ_{I2} level). For the second attribute, σ^2-1 and σ^2-2 dummies represent a moderate and significant decrease in the variance of the water supplied, respectively. Moderate decrease in the variance (σ^2-1) is considered to be at a lower magnitude than the difference (improvement) between the average $\sigma^2{}_{SQ}$ level −741,321 $(\mathrm{m}^3/\mathrm{ha/year})^2$– and the $\sigma^2{}_{I1}$ level −417,316 $(\mathrm{m}^3/\mathrm{ha/year})^2$– (i.e., with dummy variable taking value 0 if the alternative option represents no decrease compared to the $\sigma^2{}_{SQ}$, and value 1 if this option represents a decrease in the variance lower than the difference between $\sigma^2{}_{SQ}$ and $\sigma^2{}_{I1}$). Significant decrease in the variance (σ^2-2) is considered to be at a higher magnitude than that improvement (i.e., with dummy variable taking value 0 if the alternative option represents no decrease compared to the $\sigma^2{}_{SQ}$, and value 1 if this option represents a decrease in the variance higher than the difference between $\sigma^2{}_{SQ}$ and $\sigma^2{}_{I1}$)[3]. In the model estimation, we account for an individual-specific status quo (for both the mean and the variance attributes) using the information collected through the questionnaire. The attribute *Cost* is treated as linear.

Class membership was estimated based on farmers' preferences and individual characteristics of farmers, with the latter including farmers' knowledge, attitudes and opinions, etc. (see Tables A.1 and A.2 in Appendix A). The selection of the LCM was made based on model parsimony, significance levels of the parameters and interpretability with respect to policy relevance, with a 3-class solution yielding the best results according to these criteria. To select the characteristics to be included in this 3-class LCM as covariates, a two-step procedure was followed. In a first step, the full array of variables controlled were tested by using them in single-covariate LCMs. In a second step, different combinations of the variables that had proved to be significant in the first step were explored by using multiple-covariates LCMs, until the best solution in terms of fit and parsimony was reached.

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 of improvements in water supply reliability was estimated following Hanemann (1984). The alternative specific constant associated with the status quo alternative (ASC$_{SQ}$) was included in the estimation of total WTP, as it captures the utility difference between not participating in the scheme and entering a contract at baseline attribute levels. The sign of the ASC$_{SQ}$ therefore depends on whether or not the

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[3] Other specifications such as the use of three dummy variables for each attribute, as well as linear coding, were also explored, providing worse results. These results are available upon request.

expected benefits of program participation (associated with improved water supply reliability) are –on average across the sample– outweighed by the costs associated with the lowest level of payment offered in the experiment. Also, the inclusion of the $\mathrm{ASC}_{\mathrm{SQ}}$ is recommended if it can plausibly carry a behavioral interpretation (Adamowicz et al., 1998). For estimates of both marginal and total WTP, we applied the parametric bootstrapping approach by Krinsky and Robb (1986).

4. Results and discussion

4.1. Latent class model

The results of the LCM are presented in Table 4. The model shows a high goodness-of-fit (Pseudo R^2=0.626), clearly distinguishing three different classes of irrigators. Two classes (*Class 1* and *Class 2*) group respondents that are sensitive to improvements in water supply reliability. *Class 1* has a membership probability of 28.0% and groups irrigators who are willing to pay for improved water supply reliability, especially for reductions in its variance. This is reflected by the significant parameters for *Cost*, ASC_{SQ} (with the negative sign meaning that the farmer would be better-off in any alternative associated with improved water supply reliability compared to the status-quo alternative), and σ^2-1, with the latter meaning that a moderate decrease in the variance is significantly valued by the irrigators. *Class 2* has a membership probability of 24.2% and groups irrigators who are willing to pay for improved water supply reliability, either for decreased variance of and increased mean water supplied. This is evidenced by the significant parameters for *Cost*, ASC_{SQ} (with the negative sign), σ^2-1, $\mu 1$, and $\mu 2$, with the latter two coefficients referring to moderate and significant increases in the mean water supplied (equal to 3,179 m^3/ha/year and equal to or higher than 3,786 m^3/ha/year, respectively –with the current mean being 2,572 m^3/ha/year). *Class 3* has a membership probability of 47.8%, mostly grouping irrigators who systematically chose the ‘no change’ or status quo alternative (totaling 88 respondents or 44.9% of the sample used for analysis). This is confirmed by the significant and positive parameter for the ASC_{SQ}, while no attribute parameter is found to be significant. This suggests that this group of irrigators has zero WTP for improvements in water supply reliability, a fact discussed in more detail in the next sub-section.

Interestingly, the parameter σ^2-2 (significant decrease in the variance) is not significant for any of the classes, which can be interpreted in two ways: irrigators do not seem to perceive a need for a drastic reduction in the variance and/or they do not find such a reduction to be realistic given the prospects of higher variance as a result of climate change.

With regard to individual-specific characteristics, seven covariates associated with farm and farmer characteristics and farmer opinions and perceptions were included in the LCM to better explain the probability of membership to these classes. As expected, larger differences are found between *Class 2* (highly valuing improvements in water supply reliability) and *Class 3* (negligibly valuing such improvements), with *Class 1* representing an intermediate class. In particular, we find that *Class 3* irrigators have larger irrigated area (SIZE10), a higher percentage of the total farm irrigated area used for olive groves (OLIAREA), make lower use of IC's suggestions to decide how much and when to irrigate (IRRIGIC), are more frequently over 60 year-old (AGE60), and are less of the opinion that the level of water consumption for the main crop is above the average compared to other farmers (CONSUMHI).

Table 4

Latent class model (LCM).

	Class 1		*Class 2*		*Class 3*	
	Coef.	*SE*	*Coef.*	*SE*	*Coef.*	*SE*
Mean parameters						
$\mu 1$ (moderate increase in the mean)	-0.312	0.352	0.611**	0.302	0.108	1.071
$\mu 2$ (significant increase in the mean)	0.292	0.368	0.823**	0.342	-2.454	4.230
σ^2-1 (moderate decrease in the variance)	0.709*	0.399	0.444*	0.251	-3.247	5.762
σ^2-2 (significant decrease in the variance)	0.173	0.355	0.253	0.269	1.564	1.179
Cost (Per €1/ha/year)	-0.140***	0.018	-0.013***	0.003	-0.143	0.113
ASC_{SQ}	-2.472***	0.381	-2.944***	0.521	3.558***	1.362
Covariates						
AGE60: Farmer's age: 60 years or above (1=Yes; 0=No)	-0.004	0.257	-0.543**	0.276	0.547**	0.213
SIZE10: Irrigated farm area higher than 10 hectares (1=Yes; 0=No)	-0.300	0.257	-0.144	0.270	0.444**	0.215
OLIAREA: Olive groves area over total farm irrigated area (%)	-0.420	0.357	-0.060	0.376	0.480*	0.289
IRRIGIC: Procedure to decide how much and when to irrigate: As suggested by the IC staff (1=Yes; 0=No)	0.262	0.305	0.361	0.321	-0.623**	0.280
TAKEOVER: Farmer perceives that the farm will be taken over by relatives (1=Yes; 0=No)	-0.557**	0.259	0.426	0.270	0.131	0.214
CONSUMHI: Farmer perceives that the level of water consumption for his/her main crop is above the average with respect to other farmers for the same crop (1=Yes; 0=No)	-0.166	0.389	0.857**	0.340	-0.692*	0.355
COMPEUSE: Farmer agrees with the statement 'Water supply reliability is declining because of competitive uses' (1=Yes; 0=No)	0.510**	0.254	-0.528**	0.258	0.019	0.211
Class-specific constant	0.115	0.279	-0.077	0.287	-0.038	0.243
Membership probability	28.0%		24.2%		47.8%	
Log-likelihood (LL)			-575.4			
McFadden Pseudo R^2			0.626			
AIC/N			1.036			
Observations (individuals)			1,176 (196)			

Source: Own elaboration.

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

Some of these variables are closely related to *water dependency*. For example, a higher share of olive groves in a farm indicates less dependency on water: olive groves are a permanent crop with low water needs (around 2,000 m^3/ha/year) and high resilience to drought (traditionally farmed under rainfed conditions) compared to other common crops grown in Santaella IC (e.g., vegetables and cotton: with average water needs of 4,250 m^3/ha/year and 3,300 m^3/ha/year, respectively, these crops are impossible to be farmed without irrigation water). Thus, *Class 3* may be interpreted to show a lower water dependency compared to *Class 1* and *Class 2*, as farmers with a high class membership probability in *Class 3* tend to have a greater share of olive groves and other crops with lower water needs. The results regarding CONSUMHI and IRRIGIC can arguably be interpreted in a similar fashion, reflecting different levels of dependency with respect to irrigation water use (i.e., risk exposure to water shortages). These results provide some validity by showing that lower levels of dependency (risk exposure) are associated with lower intensity of preferences toward improving water supply reliability.

With regard to AGE60, our results are 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. As for SIZE10, Rigby et al. (2010) and Alcón et al. (2014) found that those irrigators managing the largest farms were willing to pay more for improved water supply reliability. In our study, a plausible interpretation is that *Class 3* irrigators (who have larger irrigated area within the IC and have zero WTP) tend to focus on the total extra costs at farm scale for improved water supply reliability rather than the per-hectare cost.

Class 1 and *2* are more similar, as there are no significant differences with regard to SIZE10, OLIAREA, and IRRIGIC. However, *Class 2* irrigators' age is most frequently below 60 year-old (AGE60) and they perceive that the level of water consumption for the main crop is above the average compared to other farmers (CONSUMHI). Therefore, younger farmers and those farmers with higher water dependency are willing to pay more for improved water supply reliability. Moreover, *Class 2* irrigators tend to disagree with the statement that water supply reliability is declining because of competitive uses for the water (COMPEUSE). As a consequence, these irrigators may believe that a considerable potential for improvements in water supply reliability exists. This would explain their sensitivity toward both moderate ($\mu 1$) and significant improvements ($\mu 2$) in the mean water supply.

Class 1 irrigators especially value a decrease in variance in water supply. This is aligned with a greater concern about increasing future competition for the resource (COMPEUSE). Additionally, *Class 1* irrigators tend to believe that their farm will not continue to be owned and managed by any relative (TAKEOVER). Therefore, farmers may be less willing to invest in their farm to ensure a higher water supply reliability.

4.2. WTP estimates

Table 5 depicts marginal WTP estimates for the attribute levels $\mu 1$, $\mu 2$, σ^2-1, σ^2-2, and ASC_{SQ}. For *Class 1* irrigators, the only WTP estimates that are significantly different from zero are σ^2-1 and ASC_{SQ}. Irrigators of this class would be willing to pay €5.0/ha/year for moderate decreases in the variance of the water supply, and have a general willingness to pay of €17.8/ha/year for improving water supply reliability. *Class 2* irrigators show significant WTP for $\mu 1$, $\mu 2$, σ^2-1, and ASC_{SQ}. Regarding the mean water supplied, they would be willing to pay €48.6/ha/year for moderate improvements ($\mu 1$), and €63.5/ha/year for significant improvements ($\mu 2$). They also show a notable WTP for moderate decreases in the variance of the water supplied (σ^2-1), with an average value of €35.5/ha/year, and have a considerable general willingness toward improving water supply reliability (ASC_{SQ}), with an average value of €244.0/ha/year. For the case of *Class 3* irrigators, as expected, neither of the attribute levels show WTP estimates significantly different from zero, thus confirming that this class groups irrigators with no (or only very low) WTP for improving water supply reliability.

Table 5

Mean marginal willingness to pay (WTP) for each class (in brackets, 95% confidence intervals) (€/ha/year)[a].

	Class 1	*Class 2*	*Class 3*	*Class weighted*
$\mu 1$ (moderate increase in the mean)	-2.3 (-7.7 – 2.5)	48.6** (2.5 – 105.1)	-4.2 (-46.6 – 54.6)	11.8** (0.5 – 25.8)
$\mu 2$ (significant increase in the mean)	1.9 (-3.7 – 6.5)	63.5** (14.9 – 109.7)	-122.0 (-317.2 – 202.2)	15.4** (3.2 – 26.9)
σ^2-*1* (moderate decrease in the variance)	5.0* (-0.9 – 10.8)	35.5* (-3.7 – 78.6)	-203.6 (-398.4 – 284.1)	9.9* (0.0 – 20.4)
σ^2-*2* (significant decrease in the variance)	1.2 (-3.6 – 6.4)	19.3 (-23.8 – 60.7)	-28.6 (-78.6 – 122.1)	6.0 (-32.0 – 50.3)
ASC_{SQ}	17.8*** (13.2 – 23.0)	244.0*** (130.5 – 425.8)	-59.6 (-235.8 – 321.8)	63.3*** (37.1 – 107.3)

Source: Own elaboration.

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

[a] Estimates are obtained using the bootstrap method (with 2000 replications) proposed by Krinsky and Robb (1986). To estimate class weighted WTP, non-significant values were set to zero.

It is not straightforward to compare these WTP estimates with previous estimates of WTP for improved water supply reliability as, unlike previous work, our study focuses on changes in the PDF of water supply. Because Mesa-Jurado et al. (2012) also focused on an irrigation district located in the same river basin, a comparison is nevertheless interesting. Mesa-Jurado et al. (2012) estimated a WTP of €0.39/ha/year to ensure a fixed amount of water of 1,000 m^3/ha in 5 out 10 years, finding a share of 23% of genuine zero bidders. Their estimates of WTP are well below the class weighted WTP estimates, which are €11.8/ha/year and €15.4/ha/year for the moderate and significant improvements considered in our study (as shown in Table 5), corresponding to a mean water supply of 3,179 m^3/ha/year and 3,786 m^3/ha/year respectively. Differences in the level of improvement and the case study area with very different cropping systems and water needs are very likely to contribute to differences in WTP estimates. With regard to the share of genuine zero bidders, although we report a higher share of this type of respondents, the results are on par with the information collected from the interviews and the board of the IC about the percentage of IC's irrigators who rejected the construction of the ponds proposed to improve water supply reliability. Apart from the different context, the lower level of mean water supply under valuation in Mesa-Jurado et al. (2012)'s work may partly explain such a difference.

Table 6 shows estimates of total WTP of the three classes, as well as the class weighted mean, for three scenarios of improvement of water supply reliability (different from the simulated scenarios I1, I2, and I3 used to generate the PDFs of water supply reliability): *SC1*, implying improvement to the attribute level σ^2-1; *SC2*, implying improvements to the attribute levels $\mu 1$ and σ^2-1; and *SC3*, implying improvements to the attribute levels $\mu 2$ and σ^2-1. All the estimates of total WTP for *Class 1* and *Class 2* are statistically significant at the 1% level, as well as for the class weighted mean, while *Class 3*'s estimates are not significantly different from zero. The class weighted total WTP for shifting from the current situation to the scenarios of improved water supply reliability is €71.6/ha/year for *SC1*, €82.8/ha/year for *SC2*, and €87.5/ha/year for *SC3*. The total mean WTP of irrigators in *Class 1* are between €19.8/ha/year and €24.0/ha/year, whereas *Class 2* irrigators show a much higher total WTP, ranging from €270.6/ha/year for *SC1* to €333.9/ha/year for *SC3*. 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 7.7-9.4% and 105.9-130.7%, respectively, for improvements in water supply reliability. These results again serve to illustrate the differences in irrigators' preferences for improving water supply reliability.

Table 6

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].

	Class 1	*Class 2*	*Class 3*	*Class weighted*
SC1: μ_{SQ} (no change in the mean);	22.0^{***}	270.6^{***}	-40.6	71.6^{***}
σ^2-1 (moderate decrease in variance)	(17.3 – 27.9)	(157.3 – 457.3)	(-534.3 – 388.4)	(44.2 – 116.3)
SC2: $\mu 1$ (moderate increase in the mean);	19.8^{***}	319.2^{***}	-36.3	82.8^{***}
σ^2-1 (moderate decrease in the variance)	(14.2 – 26.1)	(198.4 – 518.8)	(-510.0 – 360.6)	(53.3 – 131.8)
SC3: $\mu 2$ (significant increase in the mean);	24.0^{***}	333.9^{***}	-39.2	87.5^{***}
σ^2-1 (moderate decrease in the variance)	(18.8 – 29.7)	(218.6 – 519.5)	(-670.5 – 565.9)	(59.5 – 132.2)

Source: Own elaboration.

*** denotes significance at the 1% level.

[a] Estimates are obtained using the bootstrap method (with 2000 replications) proposed by Krinsky and Robb (1986). To estimate class weighted WTP, non-significant values were set to zero.

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. Due to this higher experienced individual utility, they are willing to pay additional fees for alternatives that imply increases in the mean of the PDF of water supply and reductions of the variance of the PDF.

These results reveal great differences in preferences among irrigators for improving water supply reliability. Some respondents are willing to pay nothing (*Class 3*), 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 (*Class 3*), but also many 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 this structural investment (€38/ha/year). 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, security-differentiated water rights, insurance schemes, etc.).

In particular, the results suggest that there is potential for the redesign of the water right system, moving from the current 'proportional rights' into 'priority rights', where allotments are allocated to certain user groups (i.e., those who need a high reliability or ‘senior’ rights holders) at the expense of others (i.e., those who do not need a high reliability or ‘junior’ rights holders), as already implemented in some states of Australia and Western USA. As evidenced in Freebairn and Quiggin (2006) and in Lefebvre et al. (2012), proportional rights are inefficient because they do not account for differences in the opportunity cost of water between different users. Because of this, these authors propose entitlements with different levels of reliability as a more suitable policy option. Thus, considering the heterogeneity of irrigators’ WTP for improving water supply reliability, the implementation of priority rights would provide substantial gains in terms of a more efficient risk management associated with the use of irrigation water.

5. Conclusions

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 (*Class 3*); ii) those with low WTP (*Class 1*) (e.g., €24.0/ha/year on average for shifting to a scenario of significant improvement); and iii) and those with high WTP (*Class 2*) (e.g., €333.9/ha/year on average for shifting to a scenario of significant improvement). *Class 1*'s and *Class 3*'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 well explain why the implementation of this measure was ultimately rejected. Therefore, the different preferences of the three classes of irrigators toward improving water supply reliability suggest that more targeted demand-side instruments are needed for improving water management under supply uncertainty conditions. In this sense, the redesign of the water rights system is suggested, moving from the current proportional rights into priority rights, allowing irrigators willing to pay for improving water supply reliability to enhance their current 'ordinary' rights into the new created 'senior' ones by charging them an extra annual fee.

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 characteristics, and farmer's opinions and attitudes also influence WTP for such improvements.

The results also hint at future research in several ways. For example, the analysis of irrigators' preferences for worsened (instead of improved) water supply reliability would shed light on the whole preference structure with regard to water supply reliability. Similarly, further research on the role of farmers' risk attitudes may be particularly relevant for explaining irrigators' decision-making in increased water scarcity conditions caused by the climate change. Also, investigations of preferences for improved water supply reliability should be complemented by studying the extent to which these preferences are sensitive to the instrument used to deal with uncertain water supply. This would provide further valuable information for the development of demand-side water management instruments in Mediterranean and semi-arid climate regions.

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