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

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1 **Willingness to pay for improved irrigation water supply reliability:**

2 **An approach based on probability density functions**

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6

7 **Asbtract**

8 In irrigated agricultural systems, a major source of uncertainty relates to water supply, as it  
9 significantly affects farm income. This paper investigates farmers' utility changes associated with  
10 shifts in the probability density function of water supply leading to a higher water supply reliability  
11 (higher mean and lower variance in annual water allotments). A choice experiment relying on a mean-  
12 variance approach is applied to the case study of an irrigation district of the Guadalquivir River Basin  
13 (southern Spain). To our knowledge, this is the first study using parameters of these probability  
14 density functions of water supply as choice experiment attributes to value water supply reliability.  
15 Results show that there are different types of farmers according to their willingness to pay (WTP) for  
16 improvements in water supply reliability, with some willing to pay nothing (47.8%) while others have  
17 a relatively low (28.0%) or high (24.2%) WTP. A range of factors influencing farmers' preferences  
18 toward water supply reliability are revealed, with those related to risk exposure to water availability  
19 being of special importance. The results can be used to assist the design of more efficient policy  
20 instruments to improve water supply reliability in Mediterranean and semi-arid climate regions.

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

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## 23 **1. Introduction**

24 Farmers worldwide are faced with a variety of risks that originate from various sources.  
25 Within these, production risks (mainly due to weather events affecting crop yields) and  
26 market risks (mainly due to changes in agricultural prices) are considered to be among the  
27 most important (OECD, 2011). Although price variability is found to be higher than yield  
28 variability in most countries, this is not the case in Mediterranean and semi-arid climate  
29 regions, which are subjected to significant variability of weather conditions (irregular  
30 precipitation and frequency of extreme events) (Antón and Kimura, 2011). This explains why  
31 Mediterranean agriculture is particularly vulnerable to the risk of drought, a source of  
32 uncertainty that is becoming increasingly relevant because of climate change is projected to  
33 involve an increase in the frequency and intensity of the drought events in these regions  
34 (IPCC, 2014; EC, 2017). All of these facts help to explain why irrigators in these regions are  
35 deeply concerned about uncertainty over water supply, which significantly affects economic  
36 decision-making in irrigated agriculture (Palinkas and Székely, 2008). In fact, in  
37 Mediterranean and semi-arid climate regions irrigation water availability is one of the main  
38 sources of uncertainty for irrigators, as they must take crop-mix selection and other farm  
39 management decisions without knowing for certain what their water allotments will be for the  
40 next season.

41 According to the neoclassical production theory, under certainty conditions an efficient  
42 farmer uses inputs (e.g., irrigation water) up to a level at which the marginal revenue product  
43 equals marginal costs. But under uncertainty regarding input availability and risk aversion,  
44 optimal levels of input use and output produced are lower than those expected under certainty  
45 conditions, as shown by Beare et al. (1998) for the case of irrigation water. In addition, it is  
46 worth mentioning that uncertainty over water supply impacts on farmers' choices of crop  
47 portfolio. Farmers may prefer crops whose production requires less agricultural capital

48 accumulation despite being less profitable (Lavee, 2010), and be dissuaded from making  
49 long-term investments that raise productivity (Marques et al., 2005). Thus, considering that  
50 most farmers are risk averse, under uncertainty regarding irrigation water availability,  
51 irrigators' decision-making (i.e., optimal input level use from a private point of view) cannot  
52 be considered efficient from a social welfare perspective (agricultural production and wealth  
53 generation is lower than under more certain irrigation water availability).

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

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

72 Traditionally, solutions for securing water supply have focused on the supply side, mainly  
73 through the construction of large-scale infrastructures such as reservoirs, aqueducts and  
74 pipelines to capture, store and transfer water resources to satisfy human needs (mainly for  
75 urban and agricultural uses). Thus, these supply-side policies aim at satisfying increasing  
76 water demands by means of increasing the resource availability. However, supply-side  
77 policies often do not represent a viable option anymore in Mediterranean and semi-arid  
78 climate regions. Existing water supply is frequently found to be unable to meet new demand  
79 within the basin, since the development of new sources of supply is limited by economic  
80 (disproportionately costly investment requirements) and environmental (maintenance of  
81 natural flows to conserve water related ecosystems) constraints. In these circumstances,  
82 basins are said to be ‘closed’ (Molle et al., 2010), and new demand has to be met by diverting  
83 water rights from primarily irrigators to other users. This considerably increases irrigators’  
84 risk exposure with respect to water supply availability. Indeed, closure of river basins has  
85 become so common in water scarce regions that policy-makers and academics increasingly  
86 explore demand-side instruments. These instruments aim at managing the current available  
87 resources to optimize water use efficiency and reduce water users’ (including irrigators)  
88 exposure to water availability risk. They include modernization of irrigation systems (Berbel  
89 et al., 2015), spot water markets (Calatrava and Garrido, 2005b; Debaere et al., 2014),  
90 drought water banks (Montilla-López et al., 2018), option contracts (Rey et al., 2016) and  
91 drought insurance schemes (Pérez-Blanco and Gómez, 2014).

92 In order to efficiently design demand-side management policies, information on users’  
93 preferences for water supply reliability is required. Knowledge on users’ willingness to pay  
94 (WTP) for improvements in water supply reliability can also help policy-makers to assess the  
95 potential of demand-side instruments to achieve a more efficient resource allocation. Despite  
96 its increasing policy relevance, only few papers investigate irrigators’ WTP for improved

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

115 All of these studies provide useful insights into the issue of water supply reliability,  
116 revealing interesting results related to farmers' preferences to improve water supply for  
117 irrigation. However, to a large extent, the valuation scenarios described secured or riskless  
118 amounts of water supply as alternatives to the current situation which, in our opinion, lacks  
119 realism. In these papers, the amount of water available for irrigation was considered as a  
120 deterministic variable (secured and completely reliable water supply amounts), instead of as a  
121 stochastic one with its own probability density function, which is arguably much closer to real

122 decision-making with regard to improvements in water reliability. Taking this into account,  
123 the main objective of this paper is to provide first evidence on farmers' preferences toward  
124 irrigation water supply reliability, defined as shifts in the probability density function of water  
125 supply. Specifically, this paper adds to existing literature by valuing changes in irrigators'  
126 utility associated with changes in both mean and variance of water allotments. To our  
127 knowledge, this has not been done previously.

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

## 143 **2. Case study**

### 144 *2.1. Water management in Spain: Water concessions and water allotments*

145 In Spain, the Water Act of 1985 declared all water resources to be public property  
146 administrated by public basin agencies. It was also established that any private use (e.g.,

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

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

## 167 2.2. Case study: Santaella Irrigators' Community in the Genil-Cabra irrigation district

168 The Santaella IC in the Genil-Cabra irrigation district (from now on referred simply as  
169 Santaella IC), located in the Guadalquivir River Basin (GRB, southern Spain), has been  
170 selected as case study. This irrigation district has been primarily selected for the empirical  
171 analysis due to representativeness, since it is an irrigated system sharing most of its features



172 with many other irrigated districts within the GRB. Moreover, it is worth mentioning that this  
 173 choice was also supported by empirical reasons, taking into account the availability of data  
 174 (i.e., Lorite et al., 2007; Lorite et al., 2013).

175 **Santaella IC** is a large irrigators' community (15,500 hectares) using surface water  
 176 resources delivered by the GRB agency. As many ICs within the basin, the Santaella IC was  
 177 established at the end of the 20th Century, currently operating with modern and efficient  
 178 irrigation technologies, with sprinkler and drip irrigation systems being most widely used  
 179 (Gómez-Limón et al., 2013). The main crops are olives, sunflower, vegetables (mainly garlic  
 180 and onion), wheat and cotton. The water fees paid by irrigators are calculated based on fixed  
 181 costs, covering depreciation and maintenance of infrastructures and personnel, and variable  
 182 costs, covering energy consumed for pumping, borne by the IC due to the provision of water  
 183 services. These costs are charged to irrigators separately through a binomial bill including two  
 184 components based on area (fixed costs imputation) and volumetric (variable costs imputation)  
 185 criteria. Main descriptive characteristics of Santaella IC are shown in Table 1.

186 **Table 1**

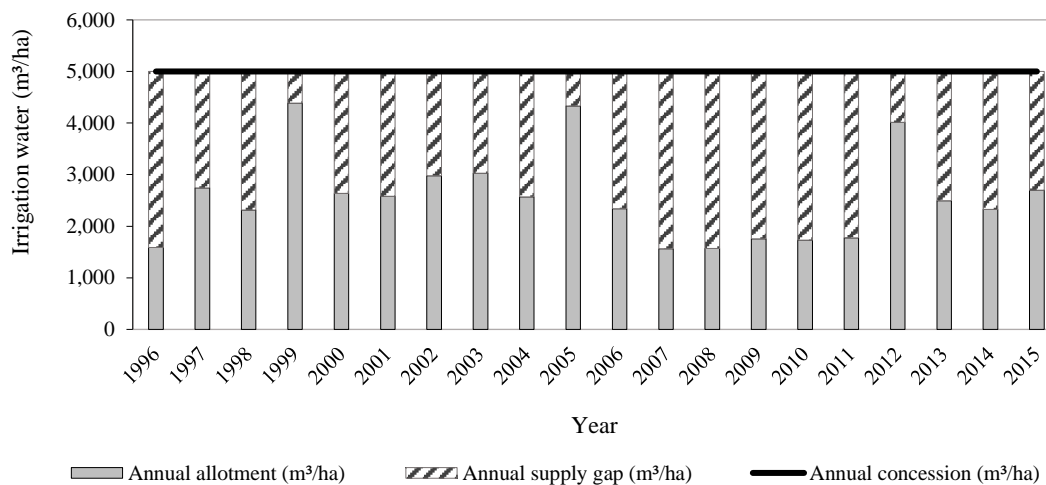
187 Descriptive characteristics of Santaella IC.

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

188 Source: Data provided by the IC.

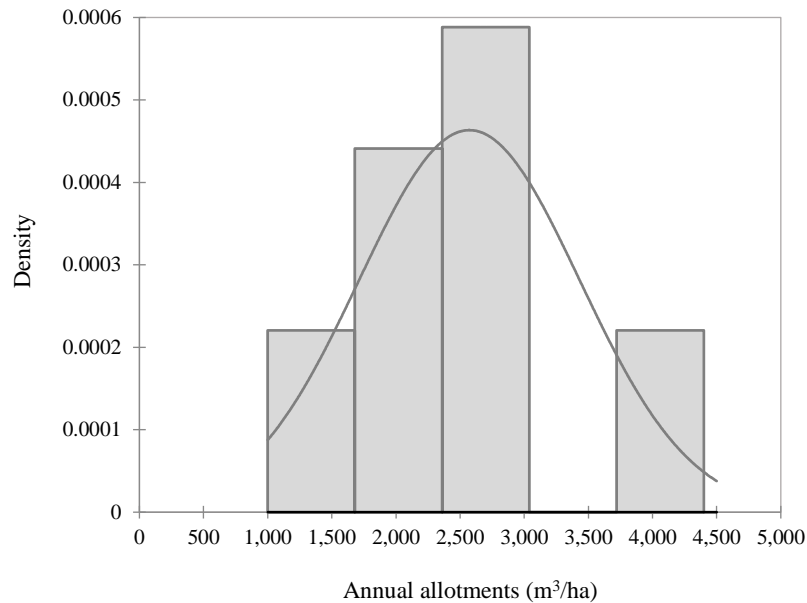
189 <sup>a</sup> Owners of irrigated land in this IC have, on average, 9.9 hectares. However, due to land leasing and other  
 190 management arrangements, irrigated farms (management unit) have, on average, 25.0 hectares.

191 As for most of the ICs in the GRB, the Santaella IC does not commonly receive the water  
 192 allotments of the legal concession of 5,000 m<sup>3</sup>/ha/year for which it is entitled. In contrast,  
 193 water allotments are generally lower, generating a considerable supply gap in most of the  
 194 years, as can be observed in Fig. 1. In fact, the average water use in the past 20 irrigation  
 195 seasons has been of 2,572 m<sup>3</sup>/ha/year (51.4% of water concession) with considerable variation  
 196 demonstrating relatively low levels of water supply reliability. Fig. 2 displays the histogram  
 197 of annual water allotments. To improve water supply availability and reliability, the board of  
 198 the IC proposed the construction of three irrigation ponds to enlarge water storing capacity,  
 199 which were projected to cost €27m (with 20%/80% private-public co-financing), resulting in  
 200 an extra-cost per irrigator of around €38/ha/year. However, this project was discarded as a  
 201 majority of the IC's members rejected it, because they were not willing to bear the increase in  
 202 farming costs required to finance it.



203  
 204

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



205

206

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

207

Water allotment can be considered as a stochastic variable with its own PDF and CDF.

208

From the series of water allotments in Santaella IC in the period from 1996 to 2015, and using

209

the software *Easyfit 5.6* (Mathwave Technologies), we have fitted data to several possible

210

distribution functions. The normal distribution function resulted as one of the most accurate

211

distribution functions to represent variability in water supply, according to the Anderson-

212

Darling (A-D) statistical test (the null hypothesis of data following normal distributions was

213

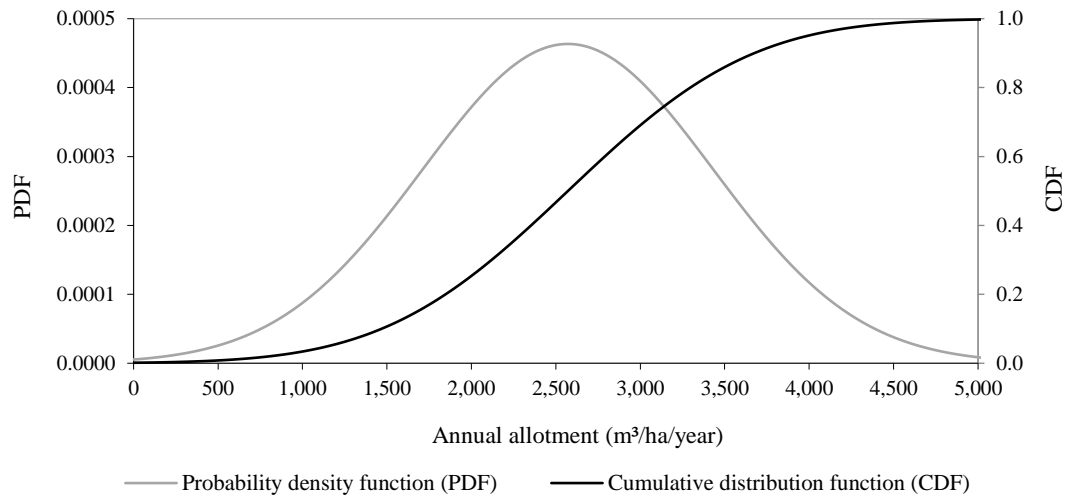
not rejected at 1% significance level). Fig. 3 shows the normal PDF and CDF for the data of

214

water allotments in Santaella IC and exhibits the two parameters characterizing the PDF:

215

location parameter  $\mu$ , equal to the mean; and scale parameter  $\sigma^2$ , equal to the variance.



216  
217  
218

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

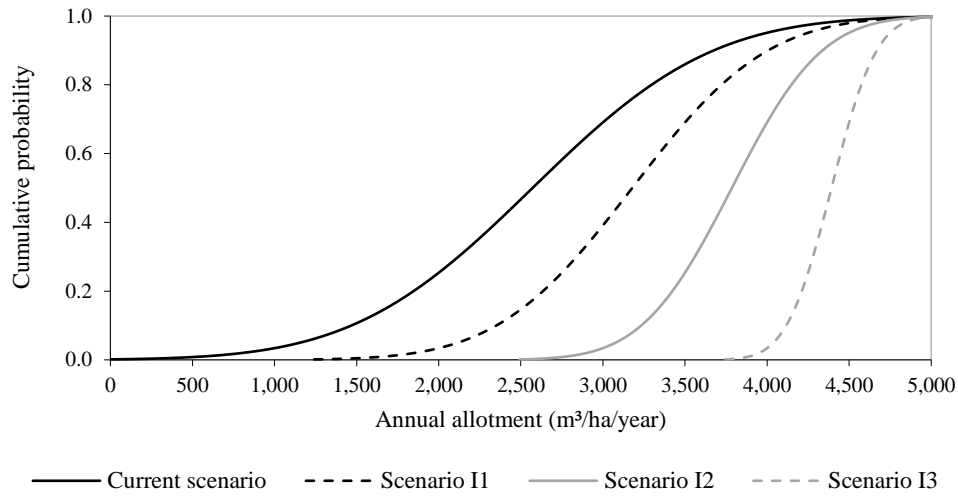
219 **3. Method**

220 *3.1. Scenarios setting*

221 The Hydrological Plan for the GRB (CHG, 2015) establishes the concept of ‘quantitative  
222 gap’ as the difference between water concession and water allotment in a given demand unit  
223 (e.g., an irrigation district), and may be calculated annually, biannually or decennially. Using  
224 water allotment data for the period 1996-2015, this gap has been calculated annually for the  
225 irrigation district selected as case study (Santaella IC) to characterize the current scenario, as  
226 shown in Fig. 1. Based on these calculations, three scenarios of improved water supply  
227 reliability were simulated: *scenario I1*, *scenario I2* and *scenario I3*, where annual gaps or  
228 differences between concession and allotment are reduced each year by 25%, 50% and 75%,  
229 respectively, compared to the current situation. These scenarios are used for the analysis of  
230 irrigators’ WTP for improvements in their water supply reliability.

231 Water allotments data resulting from the suggested improvement scenarios were fitted to  
232 normal PDFs and normal CDFs also using *Easyfit 5.6*. In all cases, data were consistent with

233 normal distribution functions as proved with an A-D statistical test. For illustrative purposes,  
 234 the resulting normal CDFs are shown in Fig. 4.



235  
 236 **Fig. 4.** Normal CDFs in Santaella IC in current scenario and in the improved scenarios (*I1*, *I2*, *I3*).

237 Table 2 shows  $\mu$  and  $\sigma^2$  parameters of the normal distribution functions fitted for each  
 238 scenario. Other useful descriptive statistics, such as 5th, 25th and 50th percentiles, are also  
 239 provided.

240 **Table 2**

241 Estimated statistics of the probability density functions for the different water reliability scenarios in  
 242 Santaella IC (m<sup>3</sup>/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%)
$\mu$	2,572	3,179	3,786	4,393
$\sigma^2$	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

243 Source: Own elaboration using irrigators' community data.

244 *3.2. Mean-variance approach*

245 The mean-variance approach (Levy and Markowitz, 1979) was proposed for financial  
246 portfolio selection in order to help investors to maximize the financial asset's return while  
247 minimizing its risk. In fact, this approach has been widely proved to be consistent with  
248 expected utility theory (Markowitz, 2014), thus providing a sound theoretical framework for  
249 analyzing the decision-making under risk beyond financial analysis, becoming one of the  
250 most widespread approaches in applied economics to model decision-making under risk  
251 (Hardaker et al., 2004). This framework generally assumes that individuals evaluate decisions  
252 based on the first two moments of the probability distribution function, the mean and the  
253 variance, being the former a direct and positive source of utility to the individuals, while the  
254 latter is a direct source of disutility. In particular in our study, a higher mean in water  
255 allotments produces an increase in irrigators' utility, while a higher variance of water  
256 allotments generates disutility to irrigators because it implies an increase of uncertainty over  
257 water supply, considering that irrigators are risk averse (Nauges et al., 2016).

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

268 The mean-variance approach has been scarcely incorporated in choice experiments with  
269 applications mainly in transport research related to estimating WTP for improvements in  
270 travel time reliability (Li et al., 2010). In agricultural and environmental domains, only few  
271 studies follow this methodological framework, despite the stochastic features of many of the  
272 attributes valued in application within these fields. An example that is worth mentioning is  
273 Gallardo et al. (2009), who used the mean-variance approach in a choice experiment to  
274 determine millers' preferences for the level and variability of winter wheat attributes. As far  
275 as the authors are aware, there is no study to date on water supply reliability adopting the  
276 framework of the mean-variance approach.

### 277 *3.3. Choice experiment*

278 The choice experiment method is a stated preference valuation technique based on  
279 Lancasterian consumer theory of value (Lancaster, 1966), with the econometric basis of the  
280 approach relying on random utility theory (McFadden, 1974). Hensher et al. (2005) provide  
281 an extensive explanation of the method's theory and practice. This method has been  
282 extensively used to analyze farmers' preferences (see Villanueva et al., 2017, for a review),  
283 with some works focusing on water supply reliability (namely, Rigby et al., 2010; Alcón et  
284 al., 2014; Bell et al., 2014).

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

287 **Table 3**

288 Attributes and levels used in the choice experiment.

Attribute	Explanation	Levels
$\mu$ parameter	$\mu$ 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 <sup>3</sup> /ha/year) (i.e., $\mu$ 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)
$\sigma^2$ parameter	$\sigma^2$ 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 <sup>3</sup> /ha/year) <sup>2</sup> ) (i.e., $\sigma^2$ 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 ( <i>Cost</i> )	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

289 Source: Own elaboration.

290 The two non-monetary attributes directly associated with water supply reliability are the  
 291 parameters of the normal PDF ( $\mu$  and  $\sigma^2$ ) of water supply reliability. Thus, the levels of these  
 292 attributes represent possible changes in the PDF for water supply reliability in the irrigation  
 293 district. For this purpose, attribute levels considered are linked to the changes referred to the  
 294 abovementioned scenarios of improved water supply reliability, in addition to the PDF for  
 295 water supply of the current situation. For the attribute related to  $\mu$  (location parameter of the  
 296 normal PDF of water supply reliability), the levels are  $\mu_{SQ}$ ,  $\mu_{I1}$ ,  $\mu_{I2}$  and  $\mu_{I3}$ . The levels of the  
 297 attribute  $\sigma^2$  (scale parameter of the normal PDF) are  $\sigma^2_{SQ}$ ,  $\sigma^2_{I1}$ ,  $\sigma^2_{I2}$  and  $\sigma^2_{I3}$ . The values of  
 298 these levels for the irrigation district analyzed are shown in Table 2 and Table 3.

299 The monetary attribute consisted of a yearly additional payment to improve water supply  
 300 reliability. The monetary attribute levels were defined in relative terms of current average  
 301 expense for irrigation water (€255.5/ha/year), using the following six levels: 2%, 5%, 10%,  
 302 20%, 30% and 50%. These levels correspond to the following absolute terms (after rounding):  
 303 €5, €10, €25, €50, €75 and €125 per hectare and year. [These levels were initially chosen](#)  
 304 [considering both value estimates previously obtained in the literature and local stakeholders'](#)



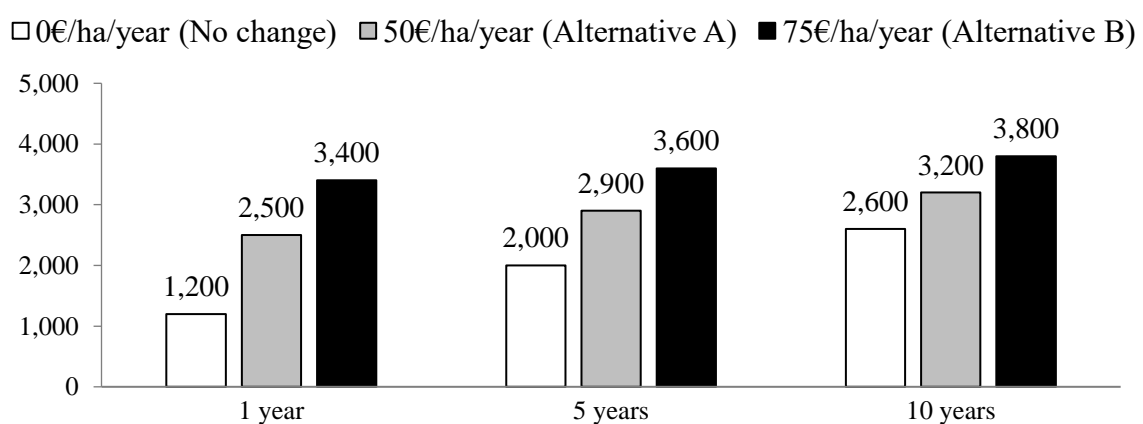
305 opinion. Moreover, these levels were checked during the pre-test in order to confirm they  
 306 cover the whole range of respondents' WTP in the case study area.

307 Because the parameterization of the normal PDF (mainly the attribute  $\sigma^2$ ) is abstract and  
 308 cannot be directly understood by farmers, the combinations of the levels of the attributes  $\mu$   
 309 and  $\sigma^2$  that characterize changes in the PDF of water supply were shown through three points  
 310 of the CDF corresponding to 5th, 25th and 50th percentiles. Presented in this way, farmers  
 311 were able to understand the different degree of water supply reliability reflected by each  
 312 combination of attribute levels. For example, in an alternative including the combination of  
 313 the levels  $\mu_{11}$  and  $\sigma^2_{12}$  (Alternative A in the example of choice card presented in Fig. 5),  
 314 farmers were shown the following information: in 1 year out of 20 years they would receive  
 315 less than 2,500 m<sup>3</sup>/ha/year; in 5 years out of 20 years they would receive less than 2,900  
 316 m<sup>3</sup>/ha/year; and in 10 years out of 20 years they would receive less than 3,200 m<sup>3</sup>/ha/year (all  
 317 figures have been rounded to 100s). As for the scenarios, the information regarding 5th, 25th  
 318 and 50th percentiles were elicited as a result of representing normal PDF in the *Easyfit 5.6*  
 319 software using the different combinations of the levels of the two attributes.

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Water supply reliability: Out of 20 years... (in m<sup>3</sup>/ha/year)

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I would choose (please tick one):

- No change (SQ)       Alternative A       Alternative B

---

320 Alternatives considered: *No change*=( $\mu_{SQ}, \sigma^2_{SQ}$ ); *Alternative A*=( $\mu_{11}, \sigma^2_{12}$ ); *Alternative B*=( $\mu_{12}, \sigma^2_{13}$ ).

321 **Fig. 5.** Example of choice card.

322 *3.4. Experimental design and data gathering*

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

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

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

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

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<sup>2</sup> 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).

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

### 349 *3.5. Econometric specification*

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

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

$$U_{jnt|s} = \beta_s X_{jnt} + \varepsilon_{jnt} \quad (1)$$

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

$$P_n([y_1, y_2, \dots, y_T]) = \sum_{s=1}^S \left[ \frac{\exp(\alpha_s Z_n)}{\sum_{s=1}^S \exp(\alpha_s Z_n)} \right] \left[ \prod_t \frac{\exp(\beta_s X_{jnt})}{\sum_{j=1}^J \exp(\beta_s X_{jnt})} \right] \quad s = 1, \dots, S \quad (2)$$

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

377 In our empirical approach, the attributes  $\mu$  and  $\sigma^2$  are treated as dummy variables, including  
378 two levels for each. For the first attribute, the dummy variable  $\mu_1$  represents a moderate  
379 improvement in the mean water supplied (corresponding to an average of 3,179 m<sup>3</sup>/ha/year,  
380 i.e., the  $\mu_{11}$  level), while the dummy variable  $\mu_2$  represents a significant improvement in the  
381 mean water supplied (corresponding to an average equal to or higher than 3,786 m<sup>3</sup>/ha/year,  
382 i.e., the  $\mu_{12}$  level). For the second attribute,  $\sigma^2-1$  and  $\sigma^2-2$  dummies represent a moderate and  
383 significant decrease in the variance of the water supplied, respectively. **Moderate decrease in**  
384 **the variance ( $\sigma^2-1$ ) is considered to be at a lower magnitude than the difference**  
385 **(improvement) between the average  $\sigma^2_{SQ}$  level  $-741,321$  (m<sup>3</sup>/ha/year)<sup>2</sup>– and the  $\sigma^2_{I1}$  level**  
386  **$-417,316$  (m<sup>3</sup>/ha/year)<sup>2</sup>– (i.e., with dummy variable taking value 0 if the alternative option**  
387 **represents no decrease compared to the  $\sigma^2_{SQ}$ , and value 1 if this option represents a decrease**  
388 **in the variance lower than the difference between  $\sigma^2_{SQ}$  and  $\sigma^2_{I1}$ ). Significant decrease in the**

389 variance ( $\sigma^2$ -2) is considered to be at a higher magnitude than that improvement (i.e., with  
390 dummy variable taking value 0 if the alternative option represents no decrease compared to  
391 the  $\sigma^2_{SQ}$ , and value 1 if this option represents a decrease in the variance higher than the  
392 difference between  $\sigma^2_{SQ}$  and  $\sigma^2_{I1}$ )<sup>3</sup>. In the model estimation, we account for an individual-  
393 specific status quo (for both the mean and the variance attributes) using the information  
394 collected through the questionnaire. The attribute *Cost* is treated as linear.

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

405 Marginal WTP was estimated by calculating the ratio of the coefficient of the non-  
406 monetary attribute ( $\mu$  or  $\sigma^2$ ) to the negative of the coefficient of the monetary attribute (*Cost*)  
407 (Hensher et al., 2005). Total WTP for scenarios of improvements in water supply reliability  
408 was estimated following Hanemann (1984). The alternative specific constant associated with  
409 the status quo alternative ( $ASC_{SQ}$ ) was included in the estimation of total WTP, as it captures  
410 the utility difference between not participating in the scheme and entering a contract at  
411 baseline attribute levels. The sign of the  $ASC_{SQ}$  therefore depends on whether or not the

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<sup>3</sup> 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.

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

#### 418 **4. Results and discussion**

##### 419 *4.1. Latent class model*

420 The results of the LCM are presented in Table 4. The model shows a high goodness-of-fit  
421 (Pseudo  $R^2=0.626$ ), clearly distinguishing three different classes of irrigators. Two classes  
422 (*Class 1* and *Class 2*) group respondents that are sensitive to improvements in water supply  
423 reliability. *Class 1* has a membership probability of 28.0% and groups irrigators who are  
424 willing to pay for improved water supply reliability, especially for reductions in its variance.  
425 This is reflected by the significant parameters for *Cost*,  $ASC_{SQ}$  (with the negative sign  
426 meaning that the farmer would be better-off in any alternative associated with improved water  
427 supply reliability compared to the status-quo alternative), and  $\sigma^2-1$ , with the latter meaning  
428 that a moderate decrease in the variance is significantly valued by the irrigators. *Class 2* has a  
429 membership probability of 24.2% and groups irrigators who are willing to pay for improved  
430 water supply reliability, either for decreased variance of and increased mean water supplied.  
431 This is evidenced by the significant parameters for *Cost*,  $ASC_{SQ}$  (with the negative sign),  $\sigma^2-1$ ,  
432  $\mu 1$ , and  $\mu 2$ , with the latter two coefficients referring to moderate and significant increases in  
433 the mean water supplied (equal to 3,179 m<sup>3</sup>/ha/year and equal to or higher than 3,786  
434 m<sup>3</sup>/ha/year, respectively –with the current mean being 2,572 m<sup>3</sup>/ha/year). *Class 3* has a  
435 membership probability of 47.8%, mostly grouping irrigators who systematically chose the  
436 ‘no change’ or status quo alternative (totaling 88 respondents or 44.9% of the sample used for

437 analysis). This is confirmed by the significant and positive parameter for the  $ASC_{SQ}$ , while no  
438 attribute parameter is found to be significant. This suggests that this group of irrigators has  
439 zero WTP for improvements in water supply reliability, a fact discussed in more detail in the  
440 next sub-section.

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

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

456 **Table 4**

457 Latent class model (LCM).

	Class 1		Class 2		Class 3	
	Coef.	SE	Coef.	SE	Coef.	SE
<i>Mean parameters</i>						
$\mu 1$ (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
$\sigma^2-1$ (moderate decrease in the variance)	0.709*	0.399	0.444*	0.251	-3.247	5.762
$\sigma^2-2$ (significant decrease in the variance)	0.173	0.355	0.253	0.269	1.564	1.179
<i>Cost</i> (Per €1/ha/year)	-0.140***	0.018	-0.013***	0.003	-0.143	0.113
<i>ASC<sub>sq</sub></i>	-2.472***	0.381	-2.944***	0.521	3.558***	1.362
<i>Covariates</i>						
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 <sup>2</sup>			0.626			
AIC/N			1.036			
Observations (individuals)			1,176 (196)			

458 Source: Own elaboration.

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

460 Some of these variables are closely related to *water dependency*. For example, a higher  
461 share of olive groves in a farm indicates less dependency on water: olive groves are a  
462 permanent crop with low water needs (around 2,000 m<sup>3</sup>/ha/year) and high resilience to



463 drought (traditionally farmed under rainfed conditions) compared to other common crops  
464 grown in Santaella IC (e.g., vegetables and cotton: with average water needs of 4,250  
465 m<sup>3</sup>/ha/year and 3,300 m<sup>3</sup>/ha/year, respectively, these crops are impossible to be farmed  
466 without irrigation water). Thus, *Class 3* may be interpreted to show a lower water dependency  
467 compared to *Class 1* and *Class 2*, as farmers with a high class membership probability in  
468 *Class 3* tend to have a greater share of olive groves and other crops with lower water needs.  
469 The results regarding CONSUMHI and IRRIGIC can arguably be interpreted in a similar  
470 fashion, reflecting different levels of dependency with respect to irrigation water use (i.e., risk  
471 exposure to water shortages). These results provide some validity by showing that lower  
472 levels of dependency (risk exposure) are associated with lower intensity of preferences toward  
473 improving water supply reliability.

474 With regard to AGE60, our results are consistent with Mesa-Jurado et al. (2012) and Alcón  
475 et al. (2014), who showed that older irrigators tend to be less likely to pay for improvements  
476 in water supply reliability. As for SIZE10, Rigby et al. (2010) and Alcón et al. (2014) found  
477 that those irrigators managing the largest farms were willing to pay more for improved water  
478 supply reliability. In our study, a plausible interpretation is that *Class 3* irrigators (who have  
479 larger irrigated area within the IC and have zero WTP) tend to focus on the total extra costs at  
480 farm scale for improved water supply reliability rather than the per-hectare cost.

481 *Class 1* and *2* are more similar, as there are no significant differences with regard to  
482 SIZE10, OLIAREA, and IRRIGIC. However, *Class 2* irrigators' age is most frequently below  
483 60 year-old (AGE60) and they perceive that the level of water consumption for the main crop  
484 is above the average compared to other farmers (CONSUMHI). Therefore, younger farmers  
485 and those farmers with higher water dependency are willing to pay more for improved water  
486 supply reliability. Moreover, *Class 2* irrigators tend to disagree with the statement that water  
487 supply reliability is declining because of competitive uses for the water (COMPEUSE). As a

488 consequence, these irrigators may believe that a considerable potential for improvements in  
489 water supply reliability exists. This would explain their sensitivity toward both moderate ( $\mu 1$ )  
490 and significant improvements ( $\mu 2$ ) in the mean water supply.

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

#### 496 4.2. WTP estimates

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

510 **Table 5**

511 Mean marginal willingness to pay (WTP) for each class (in brackets, 95% confidence intervals)  
 512 (€/ha/year)<sup>a</sup>.

	<i>Class 1</i>	<i>Class 2</i>	<i>Class 3</i>	<i>Class weighted</i>
$\mu 1$ (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)
$\sigma^2-1$ (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)
$\sigma^2-2$ (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)

513 Source: Own elaboration.

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

515 <sup>a</sup> Estimates are obtained using the bootstrap method (with 2000 replications) proposed by Krinsky and Robb  
 516 (1986). To estimate class weighted WTP, non-significant values were set to zero.

517 It is not straightforward to compare these WTP estimates with previous estimates of WTP  
 518 for improved water supply reliability as, unlike previous work, our study focuses on changes  
 519 in the PDF of water supply. Because Mesa-Jurado et al. (2012) also focused on an irrigation  
 520 district located in the same river basin, a comparison is nevertheless interesting. Mesa-Jurado  
 521 et al. (2012) estimated a WTP of €0.39/ha/year to ensure a fixed amount of water of 1,000  
 522 m<sup>3</sup>/ha in 5 out 10 years, finding a share of 23% of genuine zero bidders. Their estimates of  
 523 WTP are well below the class weighted WTP estimates, which are €11.8/ha/year and  
 524 €15.4/ha/year for the moderate and significant improvements considered in our study (as  
 525 shown in Table 5), corresponding to a mean water supply of 3,179 m<sup>3</sup>/ha/year and 3,786  
 526 m<sup>3</sup>/ha/year respectively. Differences in the level of improvement and the case study area with  
 527 very different cropping systems and water needs are very likely to contribute to differences in  
 528 WTP estimates. With regard to the share of genuine zero bidders, although we report a higher  
 529 share of this type of respondents, the results are on par with the information collected from  
 530 the interviews and the board of the IC about the percentage of IC's irrigators who rejected the

531 construction of the ponds proposed to improve water supply reliability. Apart from the  
532 different context, the lower level of mean water supply under valuation in Mesa-Jurado et al.  
533 (2012)'s work may partly explain such a difference.

534 Table 6 shows estimates of total WTP of the three classes, as well as the class weighted  
535 mean, for three scenarios of improvement of water supply reliability (different from the  
536 simulated scenarios I1, I2, and I3 used to generate the PDFs of water supply reliability): *SC1*,  
537 implying improvement to the attribute level  $\sigma^2-1$ ; *SC2*, implying improvements to the attribute  
538 levels  $\mu1$  and  $\sigma^2-1$ ; and *SC3*, implying improvements to the attribute levels  $\mu2$  and  $\sigma^2-1$ . All  
539 the estimates of total WTP for *Class 1* and *Class 2* are statistically significant at the 1% level,  
540 as well as for the class weighted mean, while *Class 3*'s estimates are not significantly  
541 different from zero. The class weighted total WTP for shifting from the current situation to  
542 the scenarios of improved water supply reliability is €71.6/ha/year for *SC1*, €82.8/ha/year for  
543 *SC2*, and €87.5/ha/year for *SC3*. The total mean WTP of irrigators in *Class 1* are between  
544 €19.8/ha/year and €24.0/ha/year, whereas *Class 2* irrigators show a much higher total WTP,  
545 ranging from €270.6/ha/year for *SC1* to €333.9/ha/year for *SC3*. If we compare these results  
546 with the total current irrigation water expenses (€255.5/ha/year), it can be inferred that *Class*  
547 *1*'s and *Class 2*'s irrigators are willing to increase their current fees by 7.7-9.4% and 105.9-  
548 130.7%, respectively, for improvements in water supply reliability. These results again serve  
549 to illustrate the differences in irrigators' preferences for improving water supply reliability.

550 **Table 6**

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

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

553 Source: Own elaboration.

554 \*\*\* denotes significance at the 1% level.

555 <sup>a</sup> Estimates are obtained using the bootstrap method (with 2000 replications) proposed by Krinsky and Robb  
 556 (1986). To estimate class weighted WTP, non-significant values were set to zero.

557 Overall, the results indicate that the majority of irrigators enjoy increases in their  
 558 individual utility by shifting from the current situation to the different scenarios of  
 559 improvement of water supply reliability. Due to this higher experienced individual utility,  
 560 they are willing to pay additional fees for alternatives that imply increases in the mean of the  
 561 PDF of water supply and reductions of the variance of the PDF.

562 These results reveal great differences in preferences among irrigators for improving water  
 563 supply reliability. Some respondents are willing to pay nothing (*Class 3*), others have low  
 564 WTP (*Class 1*), and the rest has high WTP (*Class 2*). It can be presumed that not only  
 565 irrigators with zero WTP (*Class 3*), but also many of *Class 1*'s irrigators rejected the  
 566 construction of the abovementioned ponds because of the low magnitude of their mean WTP  
 567 that is smaller than the estimated annual cost of this structural investment (€38/ha/year). This  
 568 heterogeneity of irrigators' preferences toward water supply reliability is of great interest to  
 569 policy-makers for the design of demand-side water supply instruments (water markets, water  
 570 banks, security-differentiated water rights, insurance schemes, etc.).

571 In particular, the results suggest that there is potential for the redesign of the water right  
 572 system, moving from the current 'proportional rights' into 'priority rights', where allotments

573 are allocated to certain user groups (i.e., those who need a high reliability or ‘senior’ rights  
574 holders) at the expense of others (i.e., those who do not need a high reliability or ‘junior’  
575 rights holders), as already implemented in some states of Australia and Western USA. As  
576 evidenced in Freebairn and Quiggin (2006) and in Lefebvre et al. (2012), proportional rights  
577 are inefficient because they do not account for differences in the opportunity cost of water  
578 between different users. Because of this, these authors propose entitlements with different  
579 levels of reliability as a more suitable policy option. Thus, considering the heterogeneity of  
580 irrigators’ WTP for improving water supply reliability, the implementation of priority rights  
581 would provide substantial gains in terms of a more efficient risk management associated with  
582 the use of irrigation water.

## 583 **5. Conclusions**

584 Information on irrigators’ preferences with regard to water supply reliability is very useful  
585 to design policy instruments aiming at improving the efficiency of irrigation water use under  
586 uncertainty conditions. This fact justifies why the present research examines irrigators’ WTP  
587 for improvements in water supply reliability. Compared to previous investigations into this  
588 topic that treated irrigation water supply as a deterministic variable, this study characterizes it  
589 as a stochastic variable, with its own distributional function. Thus, we add to that literature by  
590 providing more reliable estimates of irrigators’ WTP for improvements in water reliability  
591 based on changes in the probability density function of water supply using the mean-variance  
592 approach and the choice experiment.

593 The results show that the majority of irrigators obtain utility gains by shifting from the  
594 current situation to different scenarios of improvement of water supply reliability  
595 characterized by changes in the probability density function. Three different types of irrigators  
596 are distinguished according to their WTP: i) those who are not willing to pay (*Class 3*); ii)  
597 those with low WTP (*Class 1*) (e.g., €24.0/ha/year on average for shifting to a scenario of

598 significant improvement); and iii) and those with high WTP (*Class 2*) (e.g., €333.9/ha/year on  
599 average for shifting to a scenario of significant improvement). *Class 1*'s and *Class 3*'s  
600 irrigators exhibit a mean WTP for water supply reliability that is lower than the annual cost of  
601 a structural measure (three irrigation ponds) that had been proposed to improve current  
602 situation in the case study area. This may well explain why the implementation of this  
603 measure was ultimately rejected. Therefore, the different preferences of the three classes of  
604 irrigators toward improving water supply reliability suggest that more targeted demand-side  
605 instruments are needed for improving water management under supply uncertainty conditions.  
606 In this sense, the redesign of the water rights system is suggested, moving from the current  
607 proportional rights into priority rights, allowing irrigators willing to pay for improving water  
608 supply reliability to enhance their current 'ordinary' rights into the new created 'senior' ones  
609 by charging them an extra annual fee.

610 In addition, significant differences between classes are analyzed to identify factors  
611 influencing irrigators' preferences toward water supply reliability. The results suggest that  
612 farm characteristics related to irrigation water dependency (i.e., water availability risk  
613 exposure) significantly determine WTP for improving water supply reliability, showing a  
614 positive relationship (i.e., the higher the level of dependency –risk exposure–, the higher  
615 WTP). Moreover, the results show that sociodemographic variables, farm characteristics, and  
616 farmer's opinions and attitudes also influence WTP for such improvements.

617 The results also hint at future research in several ways. For example, the analysis of  
618 irrigators' preferences for worsened (instead of improved) water supply reliability would shed  
619 light on the whole preference structure with regard to water supply reliability. Similarly,  
620 further research on the role of farmers' risk attitudes may be particularly relevant for  
621 explaining irrigators' decision-making in increased water scarcity conditions caused by the  
622 climate change. Also, investigations of preferences for improved water supply reliability

623 should be complemented by studying the extent to which these preferences are sensitive to the  
624 instrument used to deal with uncertain water supply. This would provide further valuable  
625 information for the development of demand-side water management instruments in  
626 Mediterranean and semi-arid climate regions.

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