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Willingness to pay for irrigation water when groundwater is scarce

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ABSTRACT

Conversion to surface water irrigation is one of the critical initiatives to address the decline in groundwater supply. A double-bounded dichotomous choice contingent valuation survey is used to estimate producers' willingness to pay (WTP) for surface water supplied by irrigation districts in Arkansas, United States. The estimated mean WTP for irrigation water is 2.7 ¢/m^3 ($33.21/acre-foot). Comparison indicates a significant share of producers are likely to have higher WTPs for surface water than the average pumping cost in the study area. Producers located in areas with less groundwater resources have higher WTPs. Producers that are more concerned with a water shortage occurring in the state in the next 10 years have higher WTPs. A somewhat unexpected result is that participation in the Conservation Reserve Program predicts lower WTPs. One possible explanation is that farmers see the transfer of land out of crop production as a more viable financial decision when groundwater supply decreases.

1. Introduction

Diminishing groundwater resources is threatening the security of nearly half of the world's drinking water supply and 43% of the world's irrigation water supply (Van der Gun, 2012). One main solution policy makers in many countries have relied on to reduce groundwater use is to improve irrigation efficiency. However, several recent empirical studies have shown that using more efficient irrigation technologies may actually increase total farm level water use (e.g., Pfeiffer and Lin, 2014). Groundwater trading can increase the allocative efficiency by moving water to higher value users, while market-based mechanisms may increase water use by activating previously unused (sleeper) or under-used (dozer) water entitlements (Palazzo and Brozović, 2014; Wheeler et al., 2014). Conversion to surface water irrigation where surface water resources are abundantly available has the most direct impact on reducing groundwater withdrawals. Although this approach has not been widely studied in academics, it has caught the attention of policy makers both in the US (e.g., MWH, 2008; North Harris County Regional Water Authority, 2014) and in other developed countries as well as developing countries such as Bangladesh (Krupnik et al., 2016).

In areas where infrastructure needs to be constructed to deliver surface water, estimates of the economic value of irrigation water to producers would be needed to conduct cost-benefit analysis of such projects as well as assess the financial viability of surface water irrigation systems. While several studies have examined the impact of water scarcity on the market value of water, few have analyzed non-market benefit of water to agricultural users. Mesa-Jurado et al. (2012) used the contingent valuation method (CVM) to show that the willingness to pay (WTP) of farmers in the Guadalquivir River Basin in southern Spain increased under conditions of water scarcity when farmers perceived the impact of guaranteed water supply to positively influence their own welfare. Toshisuke and Hiroshi (2008) evaluated the economic value of irrigation water to urban and non-urban users in Japan and found that rural users who rely on water resources for household use and to maintain agricultural income have a higher WTP for water than urban users. Storm et al. (2011) model demand for irrigation water in the Moroccan Drâa Valley using CVM and found that producer's true WTP exceeds current water prices in the region, but also note that only small increases in cost would be politically tenable, and because demand for irrigation water is relatively inelastic such price increases would do little to prevent aquifer drawdown.

This study uses a double-bounded contingent valuation method to estimate agricultural producers' WTP for off-farm surface water in an environment of decreased availability of groundwater resources in the Mississippi Delta region of the southern United States. Our WTP findings are useful to policy makers and agricultural producers around the world where irrigated agriculture is

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critical to the economy and adaptation to decreasing groundwater supply is a concern. In particular, the results are critical for evaluating the economic viability of infrastructure projects to bring surface water to farming communities. Our analysis also examines which factors have predictive power for influencing producers' WTP for off-farm shipments of irrigation water. Both our research design and research findings are useful for understanding the potential for conversion to surface water to alleviate the pressure on groundwater.

The rest of our paper is organized as follows. The next section describes the study region. The third section presents the survey data and variables used in the empirical analyses. The fourth section outlines econometric methodology. The fifth section reports results. The final section concludes.

2. Study area

The climate of the state of Arkansas in the United States is humid and subtropical, with an average high temperature of approximately 22.2 °C (72 °F) and an average low temperature of approximately 10 °C (50 °F) (ANRC 2017). During summer months, temperatures regularly reach 37.8° (100 °F), and in winter months, temperatures often fall below 0 °C (32 °F). The region experiences an average total annual rainfall of 127 cm (50 in.). However, months with the greatest quantities of rainfall (October through May) occur outside of the growing seasons of major crops such as rice and soybean. As such, there is usually insufficient rainfall within the study region during the growing season to sustain agricultural production, causing producers to rely heavily on groundwater to meet irrigation needs.

Agricultural production is of key importance to Arkansas's economy. The value of rice, soybean, corn and cotton production totaled $2.6 billion in 2013, about 2.4% of the state's gross domestic product (English et al., 2015). Arkansas ranks first among states in terms of rice production, accounting for 49.96% of total US production (USDA-ERS, 2016). It also exports large quantities of rice and is an important player in the global rice economy (ARF, 2015; English et al., 2013; Richardson and Outlaw, 2010).

Irrigation is the most important input in Arkansas' crop production. For example, despite a widespread drought throughout much of Arkansas in 2012, Arkansas soybean farmers harvested record yields (Hightower, 2012). In 2013, Arkansas accounted for 8.9% of all cropland under irrigation in the US, and the state is the third largest user of irrigation water in the country (USDA-NASS, 2014). Irrigated hectares in Arkansas have also increased steadily over years. In 2013, Arkansas farmers irrigated about 93% of rice, soybean, corn and cotton, compared to 81% in 2003 and 87% in 2008 (USDA-NASS, 2004, 2009, 2014). Most crop production is in the Arkansas Delta located in eastern Arkansas. The area is underlain by the Mississippi River alluvial aquifer (MRVAA), which extends approximately 402 km (250 miles) from north to south and 121 km to 241 km (75–150 miles) from west to east (Czarnecki et al., 2002). The Arkansas Natural Resources Commission (ANRC, 2012) estimates that agricultural irrigation is responsible for 96% of all withdrawals from the MRVAA.

However, the continuous and unsustainable pumping has put the MRVAA in danger by withdrawing at rates greater than the natural rate of recharge. Many counties in east Arkansas have been designated as critical groundwater areas due to continued decline in groundwater levels (Arkansas Soil and Water Conservation Commission, 2003). Continued drawdown of the MRVAA, largely the result of increased irrigation to insure against drought induced losses, as in 2012, poses a threat to the continued success of water intensive crops in Arkansas (Kovacs et al., 2015). An annual gap in groundwater as large as 8.6 billion cubic meters (7.26 million acre-feet) is projected for 2050 and most of the expected shortfall is attributed to agriculture (ANRC, 2015). In focus groups conducted by the authors in November 2014 with stakeholders from east Arkansas, the decline in groundwater supply was ranked among the top concerns by producers.

To combat growing projected scarcity, the state of Arkansas and the ANRC have identified two critical initiatives in the 2014 Arkansas Water Plan Update highlight adopting conservation measures that can improve on-farm irrigation efficiency as well as infrastructure-based solutions that convert more irrigated hectares currently supplied by groundwater to surface water in eastern Arkansas (ANRC, 2015). Surface water in Arkansas is relatively abundant and is allocated to farmers based on riparian water rights.[1] The ANRC (2015) estimates that average annual excess surface water available for inter-basin transfer and non-riparian use is 9.4 billion cubic meters (7,605,800 acre-feet). Currently, the purchase of off-farm surface water is relatively rare in Arkansas. In the Farm and Ranch Irrigation survey conducted by the National Agricultural Statistics Service (NASS) of the USDA, only 245 farms (4.82%) reported utilization of off-farm surface water in Arkansas in 2012 (NASS, 2014). The per cubic meter price these produces paid ranged from less than 0.08¢ to more than 4.9¢ ($1 to $60 per acre-foot).

The Grand Prairie Area Demonstration Project and the Bayou Metro Project[2] are both important features of the Arkansas Water Plan, which are designed to supplement agricultural groundwater irrigation with surface water in the hopes of reducing groundwater withdrawals in the Grand Prairie Critical Groundwater Area and preventing decline of the deeper Sparta Aquifer, which is a critical source of drinking water for the region (ANRC, 2015). In total, ANRC (2015) estimates that the construction of needed infrastructure to shift groundwater irrigation to surface water irrigation in the nine major river basins of eastern Arkansas will cost between $3.4 and $7.7 billion. Financing these projects has grown increasingly difficult because of decreases in the availability of federal grants, cost-share and loans (ANRC, 2015). As such, understanding the nature of water use and quantifying the full value of irrigation water to agricultural producers in the Delta will be critical for continued funding and long-run success of irrigation district projects, as well as the long-run viability of agricultural production in Arkansas.

3. Data and variable definitions

The data set comes from the Arkansas Irrigation Use Survey conducted by the authors with collaborators from Mississippi State University. The survey was completed in October 2016. Survey data were collected via telephone interviews administered by the Mississippi State University Social Science Research Center. Potential survey respondents come from the water user database managed by the ANRC and all commercial crop growers identified by Dun & Bradstreet records for the state of Arkansas. Of 3712 attempted contacts, 842 resulted in calls to disabled numbers, resulting in a net sample size of 2870. Of the remaining contacts, 1321 led to no answer, busy signal or voicemail. Another 925 contacts were ineligible due to illness or language barrier or identified as non-farmer. In total, 624 contacts reached were eligible to complete the survey.

[1] In Arkansas, when land toucfhes a surface water resource (a lake, stream, river or other waterway), land owners have the right to divert water without permit if doing so does not unreasonably harm another use. Arkansas law also provides a mechanism for non-riparian owners to divert surface water with approval from the ANRC as long as the use is reasonable, beneficial and will not adversely impact the environment (ANRC 2015).

[2] These projects are expected to supply irrigation water to 15% of regions with expected groundwater gaps (ANRC 2015).

Table 1
Comparison of Census of Agriculture estimates v. Sample Response.

	2012 Census of Agriculture[a]	Arkansas Irrigation Survey
Irrigated rice	27.50%	27.51%
Irrigated soybean	49.19%	53.93%
Average operator experience (NASS) v. years of farming experience (survey)	24.47	30.91

[a] Sources: USDA NASS. 2012 Census of Agriculture.

Table 2
Variable Definitions and Summary Statistics.

Variable	Description	Mean	St. Dev.	Min.	Max.
Crowley's Ridge	Binary variable where 1 = lives in a county to the east (in part or fully) of Crowley's Ridge, 0 = not	0.3421	0.4765	0	1
Years Farming	Total years of farming experience	30.91	14.41	1	60
Years Farming, Squared	The square of total years of farming experience	1161.35	909.89	0	3600
Gross Income	Binary variable where 1 = gross income from all sources is greater than $75,000 and less than or equal to $150,000, 0=not	0.4123	0.4944	0	1
Percent Farm Income	Percent of gross income from farming	81.69	26.23	0	100
Bachelor's or Higher	Binary variable where 1 = education greater than or equal to a Bachelor's degree, 0 = not	0.5614	0.4984	0	1
Total Hectares	Total irrigated in 2015	939.2	774.5	0	4,046.8
Percent Rice	Percent irrigated rice production of total hectares in 2015	27.51	26.42	0	100
Percent Soybean	Percent irrigated soybean production of total hectares in 2015	53.93	27.37	0	100
Awareness of State Tax Credit	Binary variable where 1 = is aware of state tax credit program, 0 = not	0.4825	0.5019	0	1
Conservation, CRP	Binary variable where 1 = has participated in the Conservation Reserve Program, 0 = not	0.4912	0.5021	0	1
Groundwater Shortage	Respondent rating of the severity of water shortage in Arkansas, from 0=no shortage to 5=severe shortage, in the state	2.66	1.96	0	5

Among the eligible contacts, 255 contacts declined to participate, 7 scheduled callbacks but did not complete the survey, and 171 contacts discontinued the survey. The final sample size is 199 producers that completed the survey in its entirety. Depending on how response rate is calculated, the response rate for this survey varies from 6.87% to 32.25%. The survey has nearly 150 questions and took respondents about 30–40 min to finish by phone. The survey collected a wealth of information about producers' decision about crop production and irrigation practices. The survey also collected information on a variety of socio-economic factors.

We believe the sampling procedure is appropriate and the reasons for the attrition of sample are not likely to result in biased sample. However, because the final sample size is small, we compare our sample to the sample of the 2012 Census of Agriculture using several variables that are collected in both surveys. The comparison indicates that our sample is comparable to that of the Census. The shares of irrigated land in rice are similar between the Census of Agriculture and our sample (27.5% versus 27.51%, Table 1). The shares are also similar for soybean. The share of irrigated area in soybean is slightly higher in our sample (53.93%) than in the census (49.19%). Given the upward trend in irrigated soybean production in Arkansas, we believe that the difference is likely attributable to the 4-year gap between the two samples. In our sample, the years of farming experience ranged from one to 60 years with an average of 30.91 years. This is higher than the average in the Census of Agriculture (24.47 years). Most likely this is because the Census reports years of experience as operators rather than total years of farming experience as in our survey. We believe that these two years of experience are consistent.

In addition to the variables described above, several other variables are included in our analysis to control for the characteristics of farms and producers (Table 2). The variable total irrigated hectares under production in 2015 is included. In addition to gross income, the share of total income that comes from farming is also included to measure the importance of crop production to a respondent's livelihoods. We also measure producers' education level. The highest education attained by producers in our sample vary widely. Twenty-six respondents' highest educational attainment is high school or less, 16 had attended college but not graduated, 8 reported earning an associate's degree, and 64 reported earning a bachelor's degree or higher. In the final specification of the empirical analysis, we include a binary variable that equals one if the highest level of education of a producer is a Bachelor's (or equivalent) or higher degree. In Arkansas, Crowley's Ridge in the north divides the Delta into two distinct regions (Fig. 1); the area to the east of Crowley's Ridge is characterized by relative water abundance while the area to the west of Crowley's Ridge is characterized by relative water scarcity. County of residence is used to construct a dummy variable that equals one if the respondent lives to the east (in part or fully) of Crowley's Ridge (relative water abundant area). Out of 114 respondents, 39 indicated that they reside in a county east of Crowley's Ridge.

A set of questions were used to gauge a respondent's general awareness of water issues in the Delta. We first asked the respondent "In your opinion, do you have a groundwater shortage problem on your farm?" If the answer is "Yes," we then asked the respondent to rate the groundwater shortage problem on a 5-point scale, with 1 meaning no problem and 5 meaning severe problem. We also asked the respondent "In your opinion, do you have a groundwater shortage problem in your state?" The answer is also on a 5-point scale. Only 15% of the respondents think their farms have groundwater shortage problems. This is in sharp contrast to 71% of the respondents that think the state has groundwater shortage problems. One possible explanation for this difference is that although groundwater levels are declining in the MRVAA, the depth-to-water is still above the depth of pumps. As such, producers may not detect the decline in groundwater on their farm. Producers could better detect the decline in groundwater if flow meters were installed on their wells and a drop in the water yield were observed. In our sample, about 36% of the producers own any flow meters. Among the producers without any flow meters, 11.8% think there is groundwater shortage problem on their farm, which is lower than the share among producers with flow meters (22.2%). A t test indicates that the difference is statistically significant with a p-value of 0.026. In the final specification of the empirical analysis, we use the respondent rating of groundwater shortage in Arkansas. The

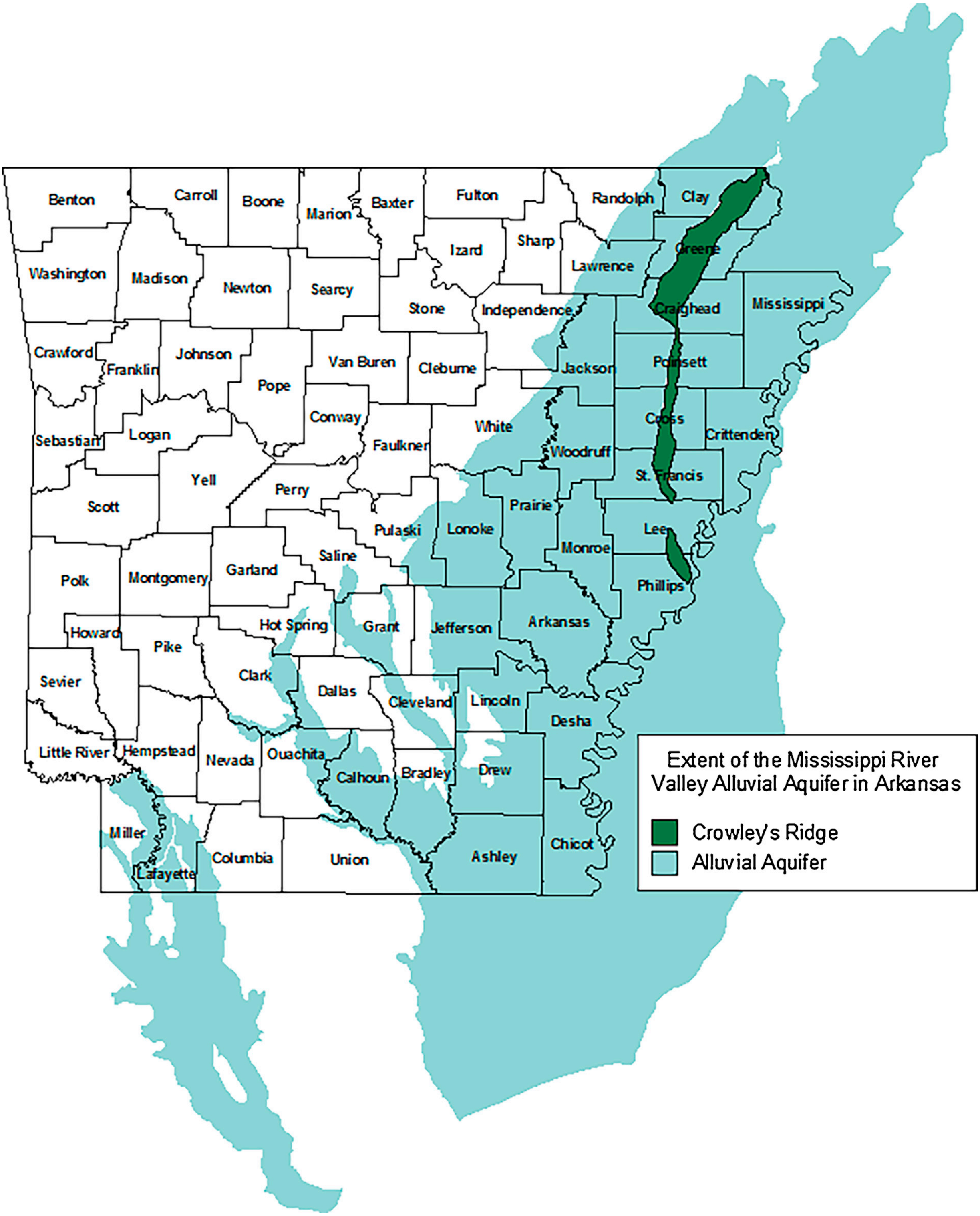

Fig. 1. Extent of the Mississippi River Valley Alluvial Aquifer and Crowley's Ridge in Arkansas.
The Mississippi River alluvial aquifer (MRVAA) is a critical source of irrigation water for agricultural production in the region. A defining feature of the region is Crowley's Ridge, which is generally recognized as a point of demarcation for relative groundwater abundance (to the east of Crowley's Ridge) and relative groundwater scarcity (to the west of Crowley's Ridge).

average rating was 2.66, and 68 respondents (59.6%) ranked the severity of shortage as three or greater.

Two variables were constructed to conservation program awareness and participation. First, to determine awareness of options for conversion to surface water irrigation, respondents were asked if they were aware of a state tax credit program that allow them to claim up to $9000 tax credit for conversions to surface water or land leveling. About 48% of the respondents were aware of this program. Respondents were also asked if they have ever participated in the Conservation Reserve Program (CRP). About 49% of the respondents indicated that they have participated in the CRP. Table 2 lists all the variable definitions and summary statistics.

Table 3
Double-Bounded Dichotomous Choice Bid Levels and Question Sequence.

	Initial Bid	Upper Bid	Lower Bid
Bid Set 1	0.8¢/m^3 ($10/aft)	1.2¢/m^3 ($15/aft)	0.4 ¢/m^3 ($5/aft)
Bid Set 2	1.6¢/m^3 ($20/aft)	2.4¢/m^3 ($30/aft)	0.8¢/m^3 ($10/aft)
Bid Set 3	2.4¢/m^3 ($30/aft)	3.6¢/m^3 ($45/aft)	1.2¢/m^3 ($15/aft)
Bid Set 4	3.2¢/m^3 ($40/aft)	4.9¢/m^3 ($60/aft)	1.6¢/m^3 ($20/aft)
Bid Set 5	4.1¢/m^3 ($50/aft)	6.1¢/m^3 ($75/aft)	2.0¢/m^3 ($25/aft)
Bid Set 6	4.9¢/m^3 ($60/aft)	7.3¢/m^3 ($90/aft)	2.4¢/m^3 ($30/aft)
Question 1	Would you be willing to pay **Initial Bid** per acre-foot of water to purchase water from an irrigation district?		
Question 2a	(If yes to Question 1) Would you be willing to pay **Upper Bid** per-acre foot of water to purchase water from an irrigation district?		
Question 2b	(If no to Question 1) Would you be willing to pay **Lower Bid** per-acre foot of water to purchase water from an irrigation district?		
Question 3	(If no to Question 2b) Would you be willing to pay 50 cents per acre foot of water to purchase water from an irrigation district?		
Question 4	(If no to Question 3) Why are you not willing to pay 50 cents per acre foot? ☐ I will not receive adequate benefits from the irrigation water ☐ I cannot afford more than 50 cents per acre foot at this time ☐ It is unfair that producers should pay more for water from the irrigation district ☐ Some other ____________________ ☐ Don't know ☐ Refused		

Note: When a producer is interviewed, one Bid Set is randomly selected to ask the producer.

3.1. WTP questions

The key information used in this study comes from the block of the survey that asked respondents a set of dichotomous choice contingent valuation questions (Table 3).

Six sets of questions are used in the survey, each with a different starting value ($10, $20, $30, $40, $50, $60). The range of WTP values proposed and units of pricing (dollars per acre-foot) were determined by examining average energy costs for groundwater withdrawals as well as the payment schedules for irrigation districts throughout the US, but primarily in California, Oregon and Washington (Board of Directors, 2013; Burt, 2007; Christian-Smith and Kaphiem, 2011; Weinberg, 1997; Wichelns, 2010). Prior to implementation of the final survey, this range of values was tested in a pilot survey and confirmed as appropriate.

To reduce starting point bias, when a respondent was interviewed, one out of the 6 sets of questions was randomly selected to ask the producer (Aprahamian et al., 2007; Flachaire and Hollard, 2006). Each producer first answered an initial question "Would you be willing to pay **$**___ per acre-foot of water to purchase water from an irrigation district?" When a respondent answered "yes" ("no"), the question was repeated at a higher (lower) bid value with a 50% increment; by increasing the interval between the first and second bid as the initial bid level increase we control for acquiescence bias (Alhassan et al., 2013; Lee et al., 2015). For respondents who answered "no" to the initial bid and "no" to the following lower bid, a third WTP question with a nominal bid amount of 0.04¢/m^3 (50¢/acre-foot) was used to determine whether true WTP was zero or if the respondent was offering a protest bid.

Out of the 199 producers that completed survey, 6 respondents refused to answer both WTP questions and 1 refused to answer the second bid level. Twenty-four respondents answered "no" to this third question. Of the remaining 169 respondents, 54 registered "don't know" responses to one or more of the proposed bid levels. All three groups of respondents were excluded from analysis. In total, 114 respondents were retained for final analysis. Table 4 reports responses at each bid level.

Table 4
Number of Yes and No responses at each bid level (¢/m^3).

	Bid	Yes	(%)	No	(%)	Total Responses
Bid Set 1	*0.4¢*	2	0.33	4	0.67	
	0.8¢	14	0.70	6	0.30	20
	1.2¢	10	0.71	4	0.29	
Bid Set 2	*0.8¢*	5	0.63	3	0.38	
	1.6¢	5	0.38	8	0.62	13
	2.4¢	4	0.80	1	0.20	
Bid Set 3	*1.2¢*	5	0.56	4	0.44	
	2.4¢	9	0.50	9	0.50	18
	3.6¢	5	0.56	4	0.44	
Bid Set 4	*1.6¢*	7	0.44	9	0.56	
	3.2¢	9	0.36	16	0.64	25
	4.9¢	6	0.67	3	0.33	
Bid Set 5	*2.0¢*	5	0.38	8	0.62	
	4.1¢	5	0.28	13	0.72	18
	6.1¢	2	0.40	3	0.60	
Bid Set 6	*2.4¢*	3	0.23	10	0.77	
	4.9¢	7	0.35	13	0.65	20
	7.3¢	1	0.14	6	0.86	

4. Econometric model

The model constructed relies on double-bounded dichotomous choice (DBDC) contingent valuation methodology, which is a simple extension of the single-bound dichotomous choice (SBDC) model. In a single-bound model, survey respondents are asked to state ("yes" or "no") if they would be willing to pay a single bid amount for a good or service. For each respondent, the probability of responding "yes" to a given bid amount is defined by

$$P_i^Y\left(b^k\right) = Pr\left\{b^k \leq \max WTP\right\} \tag{1}$$

where b^k is the offered bid amount, and the probability of a "no" response is $1 - P_i^Y\left(b^k\right)$ (Hanemann et al., 1991). Following Hanemann (1989) and Koss and Khawaja (2001), we restrict WTP to positive values and assume a logistic probability distribution. Then the probability that a respondent's WTP is greater than the offered bid amount is written as

$$\pi^Y = \frac{1}{1 + e^{-\left(\alpha + \beta b^k + \sum \delta_j Z_j\right)}} \tag{2}$$

where π^Y is the probability of a yes response, β is the bid coefficient, and δ_j is the coefficient vector corresponding to the vector of j control variables, Z.

In contrast to the SBDC model, the DBDC model requires each respondent to answer "yes" or "no" to two sequential bids. If a respondent answered "yes" to the initial question, a corresponding higher bid value was proposed, while respondents who answered "no" to the initial question were asked a corresponding lower bid value. Thus, each respondent falls into one of four categories, yes/yes (YY), yes/no (YN), no/yes (NY), or no/no (NN). We denote the probability of each response sequence as π^{YY}, π^{YN}, π^{NY} and π^{NN}, such that

$$\pi^{YY}\left(b_i^I, b_i^U\right) = Pr\left\{b_i^I \le \max WTP \text{and} b_i^U \le \max WTP\right\} \quad (3)$$

$$\pi^{YN}\left(b_i^I, b_i^U\right) = Pr\left\{b_i^I \le \max WTP \text{and} b_i^U \ge \max WTP\right\} \quad (4)$$

$$\pi^{NY}\left(b_i^I, b_i^L\right) = Pr\left\{b_i^I \ge \max WTP \text{and} b_i^L \le \max WTP\right\} \quad (5)$$

$$\pi^{NN}\left(b_i^I, b_i^L\right) = Pr\left\{b_i^I \ge \max WTP \text{and} b_i^L \ge \max WTP\right\} \quad (6)$$

where the b_i^I, b_i^U, and b_i^Lcorrespond to the initial, upper, and lower bid values, respectively, and i is the respondent index. In contrast to the single-bound dichotomous choice model, which results in only one minimum or maximum value for each respondent's WTP, the DBDC methodology allows for the construction of a bounded interval (Eqs. (4) and (5)), or minimum or maximum bound (Eqs. (3) and (6)), of each respondent's WTP, and improves the asymptotic efficiency of parameter estimates (Hanemann et al., 1991; Nayga et al., 2006). Using Eq. (2), Eqs. (3)–(6) are rewritten as

$$\pi^{YY} = \frac{1}{1+e^{-\left(\alpha+\beta b_i^U+\sum \delta_j Z_j\right)}} \quad (7)$$

$$\pi^{YN} = \frac{1}{1+e^{-\left(\alpha+\beta b_i^I+\sum \delta_j Z_j\right)}} - \frac{1}{1+e^{-\left(\alpha+\beta b_i^U+\sum \delta_j Z_j\right)}} \quad (6)$$

$$\pi^{NY} = \frac{1}{1+e^{-\left(\alpha+\beta b_i^L+\sum \delta_j Z_j\right)}} - \frac{1}{1+e^{-\left(\alpha+\beta b_i^I+\sum \delta_j Z_j\right)}} \quad (9)$$

$$\pi^{NN} = 1 - \frac{1}{1+e^{-\left(\alpha+\beta b_i^L+\sum \delta_j Z_j\right)}} \quad (10)$$

The log-likelihood function for the DBDC model, L^{DB}, is define as

$$L^{DB} = \sum_i y_i^{YY} \log \pi_i^{YY} + \sum_i y_i^{YN} \log \pi_i^{YN} + \sum_i y_i^{NY} \log \pi_i^{NY} + \sum_i y_i^{NN} \log \pi_i^{NN} \quad (11)$$

where y_i^{xx} is an indictor variable of the i^{th} respondent (Hanemann et al., 1991; Koss and Khawaja, 2001). Statistical analyses were conducted using Stata Data Analysis and Statistical Software. As shown in Koss and Khawaja (2001), using Eq. (2) and the estimation results of the DBDC model, the mean WTP can be imputed as

$$WTP = \frac{\ln\left(1+e^{\left(\alpha+\sum \delta_{ij} Z_{ij}\right)}\right)}{-\beta} \quad (12)$$

5. Results and discussion

Estimation results of the DBDC model are reported in Table 5. Goodness-of-fit of double-bounded models is best measured by the sequential classification procedure outlined by Kanninen and Khawaja (1995). The steps of sequential classification result in two values, initial correctly classified cases (ICCC) and fully, correctly classified cases (FCCC), the latter means both cases (answer to initial bid and answer to subsequent bid) are correctly specified. Correctly classified is defined as an estimated probability greater than 0.5 for an event observed in the data. FCCC is used to test the goodness-of-fit of the model. While no standard for a "good" model exists, the maximum chance criterion—the percentage of correctly classified cases that would be achieved if all responses were allocated to the group with the highest number of cases—is used as a benchmark to determine the relative predictive power of the model (Kanninen and Khawaja 1995). The computed value of FCCC for our model is 50.88% (58 cases), which exceeds the benchmark established by the maximum chance criterion, 33.33% (38 "No, No"). As such, the model specified above correctly classifies more respondents than if all responses were grouped within the most frequent case.

Table 5
Maximum Likelihood Estimation Results.

	Coefficient	Standard Error
Intercept	−1.6836	1.3816
Bid	−0.0615***	0.0076
Crowley's Ridge	−1.0586**	0.4356
Years Farming	0.2124***	0.0655
Years Farming, Squared	−0.0029***	0.0010
Gross Income	0.4595	0.3985
Percent Farm Income	−0.1928	0.7644
Bachelor's or Higher	0.5040	0.4240
Total Irrigated Hectares	−0.0001**	4.05E-05
Percent Rice	−0.1014	0.9423
Percent Soybean	0.8202	0.9423
Awareness of State Tax Credit	1.1214***	0.4175
Conservation, CRP	−1.1974***	0.4186
Groundwater Shortage	0.2044**	0.0985
Observations	114	
Wald Chi^2	28.44	
P > Chi^2	0.0048	
Log Likelihood	−135.3298	
ICCC	71.05%[a]	
FCCC	50.88%[a]	

[a] Indicates percent correctly classified responses by model is greater than the most frequently observed response.
** Significant at 5%.
*** Significant at 1%.

Although the estimated coefficient of an independent variable does not directly measure the marginal effect of that variable on WTP, the sign of the estimated coefficient does indicate the direction of the effect.[3] The coefficient of the bid variable is negative and significant at the 1% level, indicating that respondents are more likely to say no to a large bid. This result is consistent with theoretical expectations. The coefficient for the binary variable that indicates a producer is located east of Crowley's Ridge is also negative and statistically significant at the 5% level. This is probably because groundwater resources are more abundant in areas east of Crowley's Ridge and so producers are likely to exhibit lower WTP than those in the western portion of the Delta.

Coefficients of variables that measure awareness of conservation and water shortage issues are statistically significant. As expected, the coefficient of respondent's rating of groundwater shortage in the state is positive and statistically significant at the 5% level, indicating greater willingness to pay for irrigation water when groundwater resources are perceived as scarce. Respondents who indicated awareness of Arkansas' tax credit program for construction of on-farm surface water infrastructure display a greater likelihood to answer yes to a higher bid. These results highlight the importance of increasing Extension efforts to raise awareness of growing and long-term groundwater scarcity in the Delta as well as providing information that explains financial or technical assistance available to farmers who wish to transition to surface water irrigation.

A somewhat unexpected result is that Arkansas producers' WTP for irrigation water from irrigation districts decreases if they have participated in or are currently enrolled in the CRP. Previous studies have shown that producers who participate in conservation programs, such as the CRP, have better access to conservation information and make production decisions based on the impact of their choices in future periods (Lubbell et al., 2013). It appears that when

[3] Taking the derivate of both sides of Eq. (12) with respect to Z_j, we can show that $\text{sign}(\partial WTP/\partial Z_j) = \text{sign}(\partial[\alpha + \sum \delta_{ij} Z_{ij}]/\partial Z_j)$.

Table 6
Average pumping cost per cubic meter of water in the Delta, Lonoke County (highest average depth-to-groundwater in Arkansas), and Mississippi county (lowest average depth-to-groundwater in Arkansas).

Region	Average Depth-to-groundwater (Meters)[a]	Estimated Cost of Pumping (¢/m^3)[b]	Estimated WTP (¢/m^3)	Percentile in the Distribution of Estimated WTPs
Arkansas Delta	12.3 (40.49 ft)	2.2 ($27.21/aft)	2.7 ($33.21/aft)[c]	39th
Lonoke County (greatest average depth-to-groundwater in Arkansas)	25.6 (83.35 ft)	4.5 ($56.01/aft)	3.4 ($42.03/aft)[d]	92nd
Mississippi County (lowest average depth-to-groundwater in Arkansas)	4.9 (16.22 ft)	0.9 ($10.89/aft)	2.0 ($24.81/aft)[d]	6th

[a] Data on the depth-to-groundwater are obtained from Arkansas Natural Resources Commission (Swaim et al., 2016).
[b] Pumping cost is based on McDougal (2015).
[c] Mean WTP is reported.
[d] Due to small sample size in each of the two counties, median WTP is reported.

financial assistance is received to retire land, farmers may be less willing to pay for water from irrigation districts when groundwater resources become limited.

The estimated coefficient of years of farming experience and the squared term are statistically significant at 1%. In contrast to findings from previous studies that age is strictly negatively correlated with WTP for irrigation water, we find that WTP for water from irrigation districts increases with years of farming experience until approximately 38 years of experience, after which, WTP decreases with years of farming experience (Mesa-Jurado et al., 2012). The nonlinear relationship exhibited here may be the result of mixed influences of three factors. First, for both very young (inexperienced) and very old (experienced) producers, exit may be a more preferred option than continued farming with purchased off-farm water when groundwater is scarce. For young farmers, each additional year of experience increases their dependence on farming, and thus decreases their ease of exit. This explanation may contribute to the positive relationship between years of farming and WTP observed among farmers with fewer than 28 years of farming experience. Older producers, or in the sample data, those with more than 38 years of experience, are more likely to start to plan for retirement. In this case, years of farming may lead to a decrease in WTP since each additional year moves a producer closer to the age of retirement (and ease of exit increases).

Second, younger producers tend to be more concerned with the future availability of productive resources and maintaining the long-term viability of their farming operation than older producers (Mesa-Jurado et al., 2012). Since age and years of farming experience are highly correlated, this will lead to a negative relationship between years of farming experience and WTP. Third, producers who have farmed in the Delta for many decades are accustomed to “free” water, where the cost of water is only the cost of energy needed to pump groundwater from the aquifer. As such, a sense of entitlement towards water resources makes the purchase of irrigation water unpalatable and causes WTP to decline with years of farming experience. The coefficients for gross income, percent of income from farming and education were not statistically significant.

Of the three variables for crop mix, neither percent of total irrigated hectares in rice nor percent of total irrigated hectares in soybean were statistically significant. However, the coefficient for total irrigated hectares was statistically significant at the 5% significance level and negative. This result conforms to the expectation of demand theory: as total irrigated hectares increases, per hectare willingness to pay decreases. The purchase of irrigation water from irrigation districts is dependent on a producer’s bottom line (the total expenditure required to meet all irrigation needs), rather than intermediate- and long-run cropping decisions. As such, in the face of chronic groundwater shortage producers may choose to shift toward production of less water intensive crops rather than purchasing water from irrigation districts.

5.1. *Estimated willingness to pay*

Willingness to pay is estimated for each observation using Eq. (12). Of producers sampled, the minimum WTP is 0.3¢/m^3 and the maximum WTP was 6¢/m^3. The mean WTP is 3¢/m^3 (Table 6). There are few estimates of WTP for irrigation water from previous studies against which we can compare our results. However, the estimated values of WTPs are consistent with prices charged by irrigation districts in other regions of the US as well as with prices currently paid by producers in Arkansas who purchase surface water from off-farm sources (Board of Directors, 2013; Burt, 2007; Christian-Smith and Kaphiem, 2011; Weinberg, 1997; Wichelns, 2010).

One important finding is that for a significant share of the producers, the estimated WTP for surface water is likely to be greater than the energy cost they are currently paying to pump groundwater from aquifers. The Arkansas Irrigation Use Survey did not collect information on pumping cost by producer. Using the data on the depth-to-groundwater from the Natural Resources Conservation Service (Swaim et al., 2016) and energy prices, we calculate the pumping cost producers are currently paying to extract groundwater. About 72% of our sample producers use both electric and diesel pumps, 12% use exclusively electric pumps and 13% exclusively use diesel powered pumps. McDougal (2015) reported that diesel powered irrigation pumps were 2.7 times more expensive to operate than electric. The cost of water for a diesel pump from an alluvial well is 0.6¢/m^3 ($6.72/acre-foot) per 10 feet of total dynamic head (McDougal, 2015). The estimated pumping cost for the Arkansas Delta is 2.2¢/m^3 ($27.21/acre-foot), which is about the 39th percentile using the distribution of the estimated WTPs (Table 6). This means about 1%–61% of the producers have estimated WTPs higher than the estimated average pumping cost.

The comparison is also carried out for Lonoke County, which is located to the west of Crowley’s Ridge and has the greatest average depth-to-groundwater in Arkansas. Although the median WTP is lower than the average pumping cost (3.4¢/m^3 or $42.03/acre-foot versus 4.5¢/m^3 $56.01/acre-foot), at least 1%–8% of our sample producers have estimated WTPs higher than the estimated average pumping cost in the county with the greatest average depth-to-groundwater. Mississippi County is located east of Crowley’s Ridge, where the average depth-to-ground water is as shallow as 4.88 m (16 feet) and pumping costs may rarely exceed 0.9¢/m^3 ($10.89/acre-foot). The estimated median WTP is 2¢/m^3 ($24.81/acre-foot), much higher than the average pumping cost of 0.9¢/m^3 ($10.89/acre-foot). Thus, even in areas of the state where groundwater is most abundant, producers’ WTP for surface water is likely to exceed the energy cost paid to pump it from the aquifer.

6. Conclusion

Depth-to-groundwater in the MRVAA has consistently increased since early 20th century. Long-term projections indicate that only 40% of groundwater demand may be met by 2050 (ANRC, 2015). Critical initiatives to slow and reverse groundwater decline in the Delta include the adoption of more efficient irrigation technology and the construction of infrastructure to increase the use of surface water resources that are relatively abundant in the state. The objective of this study is to estimate producers' WTP for irrigation water from irrigation districts.

The study generates an estimated WTP of 2.7¢/m^3 ($33.21/acre-foot). Importantly, these estimated values are greater than the cost of pumping groundwater producers are currently paying. Our study also identifies a set of factors that influence producers' WTP. While producers are aware of growing state-level groundwater scarcity, few producers believe that scarcity is a problem which directly impacts their farm operations. Nonetheless, higher awareness seems to predict increases in producers' WTP for irrigation water. This finding highlights the importance of continued outreach by the extension service to increase awareness of water problems in Arkansas. In total, 8 variables are statistically significant. The bid value, awareness of state tax credit, if county of residence east of Crowley's Ridge, participation in the CRP, perception of groundwater shortage, years farming and its squared term, and total irrigated hectares all have statistically significant impacts on WTP.

The conclusion that participation in the CRP decreases WTP could have important policy implications. While large water savings could be achieved by increasing producers' awareness of the CRP, such practices may also decrease the level of producers' WTP for water from irrigation districts. If the downward influence on the WTPs of such programs is to the extent that irrigation districts cannot set the price of surface water to a level that allows them to recover the cost of delivering water, then the financial viability of such projects may be hampered. Similar conflict may also arise between conservation programs that focus on improving irrigation efficiency and programs that focus on conversions to surface water. Both types of programs would positively impact the sustainability of the aquifer by reducing groundwater use or moving producers towards surface water resources. However, the effectiveness or viability of one program may negatively influence the other program. If such changes limit the revenue earned by irrigation districts, the financial viability of such projects may also be limited. Policymakers need to take such unintended consequences into account when promoting these programs. For example, conservation programs that focus on improving irrigation efficiency may be more fruitful in areas where conversion to surface water is not an option (e.g., due to lack of infrastructure).

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