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Determinants of Water Source Choice for Irrigation in the Arkansas Delta

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Abstract: The use and the share of water applied from several irrigation water sources correlate with the irrigation practices in use by the peers of Arkansan farmers. From a sample of producers from an irrigation survey in Arkansas, a bivariate sample selection model accounts for how peer use of numerous irrigation practices affects the use and the share of irrigation that comes from a water source. The bivariate sample selection model controls for the bias in the statistical estimates that occur because producers who volunteer for an irrigation survey are likely to know about and use irrigation more than the population. We find that peer influence operates through multiple irrigation practices, and peer influence through an irrigation practice depends on an irrigator's location and current farm practices. For example, peer use of a tail-water recovery system and peer use of alternate wetting and drying both increase the probability of surface water use alone.

Keywords: *irrigation water source, reservoir, tail-water recovery, surface water*

Crop production in the Arkansas Delta uses substantial groundwater from the Mississippi River Valley Alluvial aquifer for irrigation (NASS 2018a), which spans several states such as Mississippi, Missouri, and Louisiana, and overdraft has led to declines in the aquifer abundance (ANRC 2014). A portfolio of sources for irrigation provides greater security for reliably meeting crop water needs throughout the growing season. Although several studies consider the determinants of irrigation practices to increase consumptive efficiency (Genius et al. 2014; Frisvold and Bai 2016; Sampson and Perry 2019a), the factors explaining the use of different irrigation water sources are less understood. We consider the use and the share of irrigation from five irrigation sources (natural surface water, surface water stored in a reservoir alone, surface water stored in a reservoir with a tail-water recovery system, groundwater, and reservoir filled by tail-water recovery alone) in the Arkansas Delta. Our focus is on the types of irrigation practices in use by a farmer's peers. We define a peer of a farmer as a family, friend, or neighbor who has used irrigation practice in the last 10 years. Conjunctive use of surface water and groundwater has been present in overdrafted parts of the Lower Mississippi River Basin (LMRB) since at least the 1950s. The most recent Arkansas Water Plan (ANRC 2014) encourages greater use of conjunctive water management to address groundwater decline in the alluvial aquifer. However, there have been no studies to our knowledge that consider the factors correlated with the use of surface water for irrigation. The role of the peer use of irrigation practices is a potential way for policy makers to make a difference in the greater adoption of surface water as an irrigation source.

The natural surface water source for irrigation refers to water taken from a bayou or other water body either on or adjacent to a farmer's field and applied directly to a field. The water source called surface water stored in a reservoir alone refers to water drawn from natural sources throughout the

Research Implications

- The use of surface water for irrigation correlates with the peer use of numerous irrigation practices.
- The use of surface water correlates with one set of peer irrigation practices, and the intensity of surface water use correlates with a different set of peer irrigation practices.
- Producers who use more surface water have less education and do not use the center pivot or zero-grade leveling practices.

year and stored in a reservoir for later irrigation. The third source is surface water stored in a reservoir with a tail-water recovery system which indicates water taken through the year from either natural sources or tail-water recovery systems and stored in a reservoir for later irrigation. The groundwater source comes from a well and is applied directly to a producer's field. The final water source is a reservoir filled by tail-water recovery alone, and this happens for the fields with no access to natural surface water. Farmers often rely on several alternative water sources since this provides greater water security for producers than reliance solely on groundwater.

We consider the share of water for irrigation from each source. A farmer may use surface water stored in a reservoir with a tail-water recovery system, but this might represent less than 5% of the water applied for irrigation. The share of water for irrigation that comes from a source reveals how much investment in that water source a farmer has made. Policy makers not only want producers to use a new irrigation source, but use that source enough that there is meaningful water conservation. Our methodological approach uses a bivariate sample selection model that allows for simultaneous consideration of a model for the use of an irrigation source and a model for the share of irrigation water applied that uses an irrigation source. A sample selection model corrects for bias by accounting for the correlation between the error terms of the models.

The likelihood of a farmer adopting irrigation or irrigation practices increases as the number of peers increases, proximity to the peer increases, and if they hear good news regarding a practice (Genius et al. 2014; Sampson and Perry 2019a; Maertens et al. 2020). Also, the information provided by extension agents influences irrigation practice adoption. The positive effect of extension visits on the adoption of drip irrigation found by Genius et al. (2014) is not borne out by studies that show extension interactions to have a negative or insignificant effect on new technology adoption (Conley and Udry 2010; Ward and Pede 2014). A literature review of the factors commonly affecting irrigation choices, including the previous studies about the role of peers, is in Appendix A1. However, there has been no examination of the determinants of the use of new water sources, especially in the Southern United States. We consider how 11 irrigation practices in the Arkansas Delta in use by peers (scientific scheduling, pivot, computerized hole selection, surge, precision leveling, end-blocking, zero grading, alternate wetting and drying, multiple-inlet, on-farm reservoirs, and tail-water recovery systems) affect the use and the share of irrigation water drawn from the five irrigation sources. The definition of the irrigation practices in the Arkansas Delta and their estimated water savings from conventional irrigation are in Table 1. A combination of several irrigation techniques in use by peers rather than a single irrigation technique has the potential to provide insights about a producer's choice of irrigation water sources. We also examine whether the influence of a peer differs by the location of a farm and the producer's current farming practices. Our findings suggest novel ways to bring together groups of producers with extension and other stakeholders to exchange information about irrigation and encourage greater use of conservation practices.

A producer considers the irrigation practices to use based on the personal view of the benefits and costs of the practices that depend on their own and their peers' experiences. The irrigation practices chosen by the producer in turn determine the irrigation sources for several reasons. One reason is that some irrigation practices and techniques operate more effectively with groundwater than surface water, namely center pivots. Another reason is that surface water use requires costly infrastructure (i.e., reservoirs and tail-water

Table 1. Definition of irrigation practices in the Arkansas Delta.

Variable	Definition	Water savings
TWR	Tail-water recovery system: collects runoff and reapplies the water to the field for a subsequent irrigation set	15%[a]
AltWetDry	Alternate wetting and drying: permitting a rice field to go dry for short periods before refilling the field with water for rice cultivation	16 to 28%[b]
CHS	Computerized hole selection: poly-pipe with alternate hole sizes to deliver water down furrows with an uneven length	25%[c]
Surge	Surge: pulsing of water along furrows by switching the flow rate during an irrigation set	51%[d]
Plevel	Precision leveling: the movement of soil to create a gentle slope for the flow of water down a furrow	--
Res	On-farm reservoirs: the storage of water collected throughout the year for irrigation later in the growing season	--
EndBlock	End-blocking: blocking or diking of the lower end of furrow irrigated fields to prevent the loss of water from the field	--
Sched	Scientific scheduling: soil moisture sensors, evapotranspiration (ET) monitors, and Woodruff charts	--
Pivot	Pivots: portable and mounted sprinkler systems	30%[e]
ZeroGrade	Zero-grading: movement of soil to create a field with no slope and a constant water level for rice production	40%[f]
MI	Multiple inlet irrigation: filling all the areas between the levees of a rice field with water at the same time	27 to 53%[g]

[a] Texas Water Development Board 2013; [b] Enriquez et al. 2021; [c] University of Arkansas Division of Agriculture 2023; [d] Nishihara and Shock 2001; [e] Stein 2011; [f] Henry et al. 2016; [g] Massey et al. 2022.

recovery systems) that may be viewed by the producer as either a complement or substitute with the irrigation practices that focus on consumptive efficiency (i.e., computerized hole selection or surge valves).

Next, we describe the study region and process for gathering the data, and this is followed by an explanation of the methods for the analysis. We finish with a section on the results followed by discussion and key findings in the conclusion.

Study Region

The Mississippi Valley Alluvial aquifer supplies most of the irrigation water for Eastern Arkansas. Regional depressions in the aquifer in the Arkansas Delta correspond to where rice is grown (ANRC 2014). Over the past decade, irrigated acres grew substantially in the Lower Mississippi Delta Region, and more than four million irrigated acres were present in Arkansas in 2018 (NASS 2018a; Kovacs et al. 2019). Climate change has the potential to increase precipitation in the winter while decreasing precipitation and increasing temperature in the growing season. The seasonal change in precipitation could increase farmer's interest in exploring water sources other than groundwater for irrigation during the spring and summer. The storage of water in a reservoir during the winter months along with the recovery and recycling of tail-water during the growing season can reduce farmer dependence on groundwater.

Gravity irrigation is common in Arkansas and includes field management practices (i.e., precision grade leveling, end blocking, and zero grade leveling) and water flow control practices (i.e., flow meters, computerized hole selection, and alternate wetting and drying) (Huang et al. 2017; Nian et al. 2020). Also common on farms that use gravity irrigation is the storage of water in reservoirs followed by the recovery and recycling of tail-water in the growing season (Kovacs et al. 2019). The use of recycled water occurs on about 18% of farms using recycled water for some irrigation (NASS 2018b). Groundwater is the only source of irrigation for three-fifths of farms and irrigated acres, but nearly nine-tenths of all farms and irrigated acres use groundwater (NASS 2018c). Almost a third of farms use on-farm surface water for irrigation, but this only constitutes a tenth of the irrigated acres. About 5% of farms use only on-farm surface water for irrigation, and this is less than 1% of the irrigated acres (NASS 2018c). Barriers to water conservation improvements are an inability to finance improvements, a landlord will not share in the cost, and improvements will not reduce costs enough to cover installation costs (NASS 2018d).

Materials and Methods

A team of agricultural scientists developed a telephone survey conducted by the Mississippi State University Social Science Research Center to understand the type of irrigation systems in the 2016 crop year. The contact information of the agricultural producers came from Survey Sampling International. There were 3,712 telephone numbers purchased for commercial crop growers from Dun & Bradstreet records for the state of Arkansas. There were at least 10 dials of each telephone number before the retirement of the number. In the four months available to conduct the survey, 913 unique phone numbers were dialed. Those reached by phone were asked at the start of the survey if they were farm operators and if they were irrigators. Of the 617 irrigators reached by phone and eligible to complete the survey, 247 refused the survey and 171 refused to continue the survey during the administration. The response rate for the survey was 32% based on the 199 fully completed surveys, but only 170 surveys had responses for all the questions in the analysis. Based on irrigators in the region reported by the Farm and Ranch Irrigation Survey (USDA NASS 2014), the margin of error for the survey is 4.6% with a 95% confidence interval (Edwards 2016).

We balance gathering a complete and extensive set of information on irrigation practices while not keeping respondents on the phone for a long conversation. The survey had nearly 150 questions and took about 40 minutes to complete. Irrigators are familiar with long surveys such as the 17-page Farm and Ranch Irrigation questionnaire and the even longer Census of Agriculture. The survey began with questions about the crops grown and general farm practices, followed by the types of irrigation practices, then the willingness to pay questions about off-farm water and on-farm surface water, and the final section asked about the peer irrigation practices and socio-demographics characteristics. Questions from all sections of the survey provide data input for addressing the research questions around the influence of the number and type of peer irrigation practices on the use and the share of land that irrigators devote to the irrigation water sources.

The summary statistics of the dependent variables for the use of an irrigation source (natural surface water, surface water stored in a reservoir alone, surface water stored in a reservoir with a tail-water recovery system, groundwater, and a reservoir filled by tail-water recovery alone) and the share of irrigation water from a source are in Tables A1 and A2 in the Appendix, respectively. The binary dependent variables in Table A1 have a value of 1 if an irrigation source is in use and 0 if an irrigation source is not in use. Figure 1 displays the information about the percentage of respondents that use an irrigation source. Groundwater (GW) is the most common irrigation source with 93.0% of respondents indicating the use of the aquifer. The next most heavily used irrigation source is natural surface water (SW) with 40.4% of respondents indicating use, followed by surface water stored in a reservoir with a tail-water recovery system (SWResTWR) at 28.7%, reservoir filled by a tail-water recovery system alone (ResTWR) at 21.1%, and surface water stored in a reservoir alone (SWRes) at 18.7%. Figure 2 and Table A2 indicate that groundwater is the source with the highest share of irrigation water in use on a farm at 73.6%.

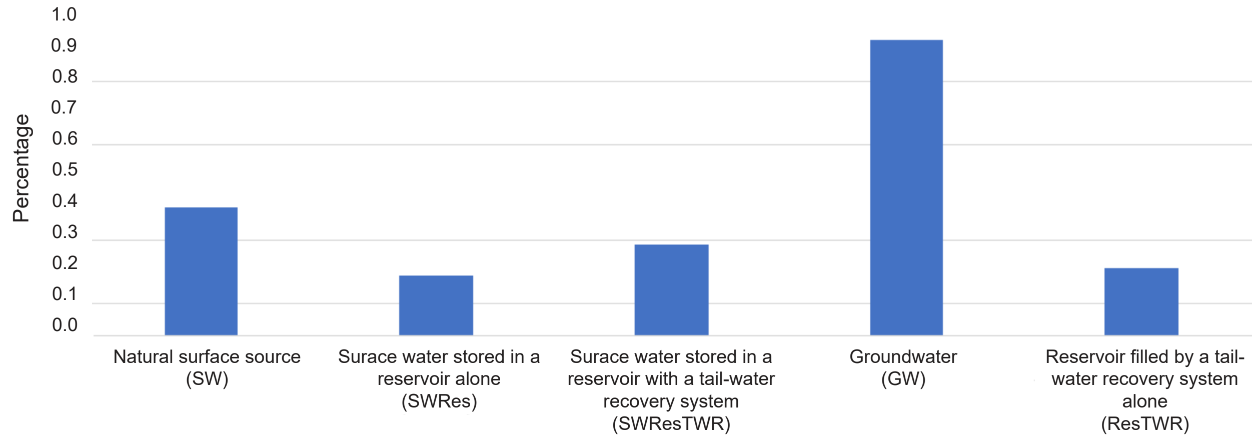

Figure 1. Percentage of respondents that use an irrigation source.

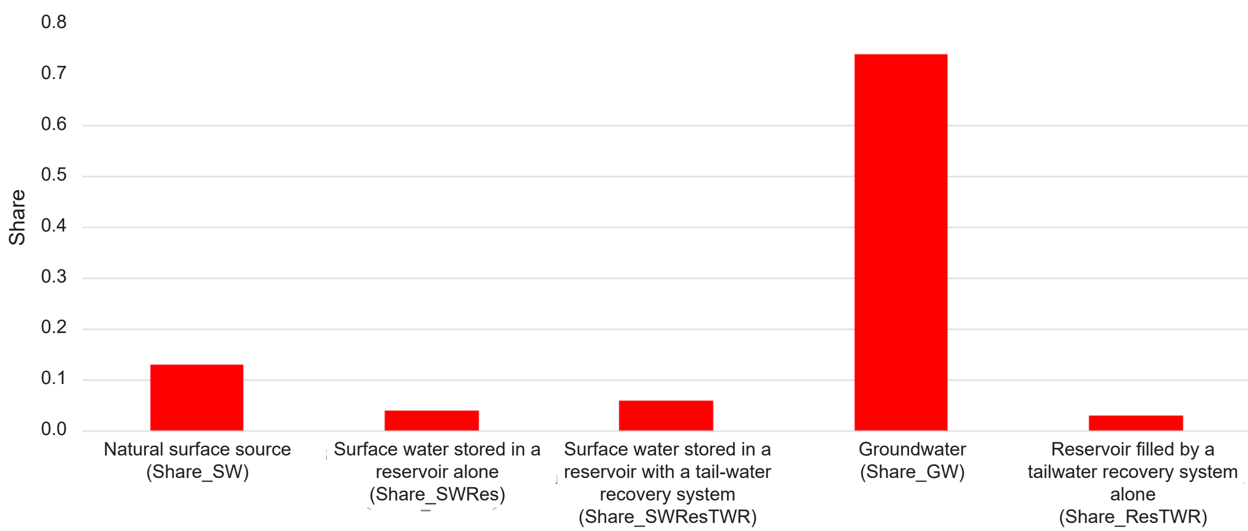

Figure 2. Share of water applied by irrigation source.

Natural surface water, surface water in a reservoir with a tail-water recovery system, reservoir filled by a tail-water recovery system alone, and surface water in a reservoir alone were on average 12.94, 6.24, 4.37, and 2.82% of a producer's source of irrigation water, respectively.

The explanatory variables for the choice of an irrigation source and the share of irrigation water from a source are in Table A3 in the Appendix. These explanatory variables have two categories 1) peer network of irrigation practice use, and 2) farm, irrigation, and socioeconomic characteristics. The variables that represent the peer network of irrigation practice use include family members, friends, or neighbors (i.e., a peer) in the past 10 years that used a type of irrigation practice. Nearly every respondent has a peer using precision leveling (PeerPlevel), around 90%, while only 35% of respondents have a peer using alternate wetting and drying for rice irrigation (PeerAltWetDry). We use the interaction variables of the peer network variables with the location and farm characteristic variables to understand how peer influence changes by location or farm practice. The Arkansas Delta locations are Crowley's Ridge (Ridge), Grand Prairie (GP), Mississippi River (River), and the North (ND) or South (SD) Delta. The Arkansas counties in each of the regions are in the definitions for those regions in Table A3. Another way we explore the influence of peer networks is through producer participation in conservation programs such as the Conservation Reserve Program (CRP) and other conservation programs (Other). The last way we modify the influence of a peer network is to consider if the primary reason for a tail-water recovery system or reservoir was financial assistance (ReasonFin). The peers of the survey respondents are not in the sample. We only know that a survey respondent has a peer that uses a particular irrigation practice. We examine if there is a correlation between the use of an irrigation practice by a peer of the survey respondent and the use of an irrigation source by the survey respondent.

Farm, irrigation, and socioeconomics characteristics include producer's education, type of pumps used on the farm, soil types, access to surface water sources, and proximity to urban areas. Although the survey did not ask for the farm size because this was deemed sensitive information to request from producers, we did ask how many irrigated acres were planted to each crop. The crop most frequently planted and that had the most planted acres was soybeans with 1,448 acres on average, but one farm had planted 12,000 acres. The second most frequently planted crop was rice with 1,058 acres on average and one farm had a maximum of 6,250 acres. Less than half report having a bachelor's degree (Bach), but more than half report having a degree related to agriculture (AgEdu). Nearly all respondents report using at least one diesel (DieselPump) and one electric pump (ElectricPump). Using information from the Soil Survey Geographic Database, on average about a quarter of the land in a county has a pH above 6 (pH>6.0). The typical county has a population of 20,000 or more and is not adjacent to a metro area according to the Rural-Urban continuum code for 2013 (USDA ERS 2013). Based on the National Hydrography Dataset, the average county has about 37 kilometers (23 miles) of canals and ditches (CanalDitch) and about 137 kilometers (85 miles) of streams and rivers (StreamRiver).

Data Analysis

Studies based on observation are rarely pure random samples (Heckman 1979). A sample of producers who volunteer to spend time on an irrigation survey likely have an interest in production with irrigation. A non-random sample results in the bias of parameter estimates that persist at large sample sizes. The bivariate sample selection model corrects for the bias by accounting for the correlation between the error in the model on the use of an irrigation source and the error in the model for the share of irrigation water applied that uses an irrigation source. The model for the use of an irrigation source has a binary dependent variable. The model for the share of irrigation water applied that uses an irrigation source has a continuous dependent variable.

The irrigation source dependent variable y_1 (e.g., =1 if use natural surface source for irrigation when considering SW), is an incompletely observed value of a latent dependent variable, y_1^* where the observation rule is

$$y_1 = \begin{cases} 1 \; if \; y_1^* > 0, \\ 0 \; if \; y_1^* \leq 0 \end{cases}$$

and a resultant outcome equation such that

$$y_2 = \begin{cases} y_2^* \; if \; y_1^* > 0 \\ - \;\; if \; y_1^* \leq 0. \end{cases}$$

This model indicates that the share of an irrigation water from an irrigation source, y_2 (e.g., when considering the share of water applied from a natural source, Share_SW), is observed when y_1^* >0 and there is no value for y_2 when $y_1^* \leq 0$. Since y_1^* and y_2^* are latent variables, the use and the share of irrigation water applied that uses an irrigation source are not observed for the population, only the sample. We then specify a linear model with additive errors for the latent variables, so

$$y_1^* = x_1'\beta_1 + \varepsilon_1,$$

$$y_2^* = x_2'\beta_2 + \varepsilon_2.$$

Bias will arise in the estimation of β_2 if ε_1 and ε_2 are correlated. However, through maximum likelihood and the assumption that the correlated errors have a joint normal distribution and are homoscedastic

$$\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \end{bmatrix} \sim \aleph \left[\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & \sigma_{12} \\ \sigma_{12} & \sigma_2^2 \end{bmatrix} \right],$$

then estimation is asymptotically efficient. The bivariate sample selection model corrects for the correlated errors that would lead to bias if the estimation of the equation for y_2^* was through ordinary least squares.

The likelihood function for the bivariate sample selection model is

$$L = \prod_{i=1}^{n} \{Pr[y_{1i}^{*} \leq 0]\}^{1-y_{1i}} \{f(y_{2i} \mid y_{1i}^{*} > 0) \times Pr[y_{1i}^{*} > 0]\}^{y_{1i}}$$

where an initial term in the irrigation source use equation is $y_{1i}^{*} \geq 0$, and the second term is the equation for the share of irrigation water applied that uses the irrigation source when $y_{1i}^{*} > 0$.

We report the marginal effects of irrigation source use as the change in the probability of use in response to a one-unit increase in an explanatory variable. The marginal effect for the share of irrigation water applied that uses an irrigation source depends indirectly on how an explanatory variable affects the use of an irrigation source and directly through the share of irrigation water applied that uses an irrigation source. Explanatory variables appearing only in the equation for the share of irrigation water applied that uses a source have a marginal effect equal to the coefficient estimate. If an explanatory variable appears only in the use equation, a unit change in the explanatory variable affects the expected value of the error term, and through correlation of the error terms in both equations, there is an expected change in y_2. When an explanatory variable appears in both equations, then the indirect effect through the use equation and the direct effect through the share of irrigation water equation result in an expected change to y_2. We conduct the maximum likelihood estimation with Stata® version 13.1 developed by StataCorp.

Results

The first two tables of results indicate the role of peer use of multiple irrigation practices (Table 2) and other farm and socioeconomic characteristics (Table 3) on the use of five irrigation water sources. The decision to use a surface water source for irrigation (a binary yes or no variable) is a first step toward the reduction of groundwater dependence, but the share of irrigation water from a surface source (a continuous variable) explains the level of investment in alternative sources of irrigation water. The last two results tables examine how peer use of multiple irrigation practices (Table 4) and the other farm and socioeconomic characteristics of the producer (Table 5) influence the share of irrigation water from the five irrigation sources. Other explanatory variables included in the analysis that did not have estimated coefficients significant at the 15% level or above have summary statistics in Table A4 and marginal effects in Tables A5 and A6.

A producer with a peer using a tail-water recovery system (PeerTWR) increases the likelihood of that producer using natural surface water (SW) by 38% (Table 2). However, if the producer uses a tail-water recovery system (TWR), this has no influence on the likelihood that the producer uses natural surface water. In fact, Table 2 indicates that no irrigation practice that the farmer uses themselves has an influence on the likelihood that the producer uses natural surface water, surface water with a reservoir alone (SWRes), groundwater (GW), or a reservoir filled by a tail-water recovery system alone (ResTWR). A producer with a peer using alternate wetting and drying (PeerAltWetDry) is 27% more likely to use natural surface water. The peer effect differs by location and whether financial assistance was a primary reason for using a reservoir or tail-water recovery system. We control for historical weather patterns in the analysis, and the location specific influence of the peer effects has more to do with the historical differences in crops grown and agricultural development across the wide geographic area. A producer with a peer using a tail-water recovery system who lives along the Mississippi River (PeerTWR*River) is 57% less likely to use natural surface water. A producer with a peer using computerized hole selection, and whose primary reason for using a reservoir or tail-water recovery system is financial assistance (PeerCHS*ReasonFin), is 26% more likely to use natural surface water.

A producer with a peer using surge (PeerSurge) decreases the likelihood of that producer using surface water with a reservoir alone by 9%. A producer with a peer using a tail-water recovery system and who participates in a conservation program other than the conservation reserve program, or the environmental quality incentives program (PeerTWR*Other) is 11% less likely to use surface water with a reservoir alone. A producer with a peer using computerized hole selection and who lives in the North Delta (PeerCHS*ND) is 24% more likely to use surface water with a reservoir alone. The lower precipitation in the

North Delta than in the South may partly explain this (PRISM 2022). A producer with a peer using a tail-water recovery system (PeerTWR) increases the likelihood of that producer using surface water with a reservoir and tail-water recovery system (SWResTWR) by 21%. A producer with a peer using precision leveling (PeerPlevel) increases the likelihood of a producer using surface water with a reservoir and tail-water recovery system by 23%. A producer with a peer using a reservoir and who lives in the North Delta (PeerRes*ND) is 19% less likely to use surface water with a reservoir and tail-water recovery system. The summary statistics for the Arkansas Delta regions in Table A3 indicate that 12% of the respondents come from the North Delta region, 32% from counties around Crowley's Ridge, 7% from South Delta counties, and the rest from other Delta counties. Three irrigation practices (alternate wetting and drying (AltWetDry), precision leveling (Plevel), and reservoirs (Res)) a producer uses themselves correlate positively with the likelihood of surface water use with a reservoir and tail-water recovery system.

A producer with a peer using end-blocking (PeerEndBlock) increases the likelihood of that producer using groundwater by 7%. A producer with a peer using alternate wetting and drying (PeerAltWetDry) decreases the likelihood of a producer using a reservoir filled by a tail-water recovery system alone by 10%. A producer with a peer using end-blocking increases the likelihood of a producer using a reservoir filled by a tail-water recovery system alone by 5%. A producer with a peer using scientific scheduling and who lives in the Crowley's Ridge region (PeerSched*Ridge) is 10% more likely to use a reservoir filled by a tail-water recovery system alone. A producer with a peer using scientific scheduling, and whose primary reason for using a reservoir or tail-water recovery system is financial assistance (Peer*ReasonFin), is 22% less likely to use a reservoir filled by a tail-water recovery system alone.

Table 2. Marginal effects[1] for the peer network variables to explain the use of an irrigation water source.

Variable	SW	SWRes	SWResTWR	GW	ResTWR
PeerTWR	0.38 (0.02)[b]	0.06 (0.21)	0.21 (0.09)[c]		
PeerAltWetDry	0.27 (0.06)[c]				-0.10 (0.06)[c]
PeerCHS	0.15 (0.16)	-0.09 (0.12)			
PeerSurge		-0.09 (0.09)[c]			
PeerPlevel			0.23 (0.12)[c]		
PeerRes			0.14 (0.17)		
PeerEndBlock				0.07 (0.09)[c]	0.05 (0.10)[c]
PeerSched					-0.04 (0.21)
PeerSched*Ridge					0.10 (0.10)[c]
PeerSched*ReasonFin					-0.22 (0.10)[c]
PeerRes*ND			-0.19 (0.07)[c]		
PeerTWR*River	-0.57 (0.03)[b]				
PeerTWR*Other		-0.11 (0.08)[c]			
PeerCHS*ND		0.24 (0.02)[b]			
PeerCHS*ReasonFin	0.26 (0.08)[c]				
PeerAltWetDry*ReasonFin	-0.31 (0.08)[c]				
Pseudo R^2	0.63	0.46	0.45	0.32	0.51

Number of observations: 170. Significance values: [a] = 1%, [b] = 5%, [c] = 10%. P-values from the probit model estimates in parentheses. [1]The marginal effects for the peer variables that also have interaction variables are the marginal effects assuming the interaction variables are zero. For example, the marginal effect on PeerTWR in the SW column assumes the variable River is zero. The marginal effect for PeerTWR*River in the SW column assumes that the variables PeerTWR and River are both one.

Table 3. Marginal effects for the farm, irrigation, and socioeconomics variables to explain the use of an irrigation water source.

Variable	SW	SWRes	SWResTWR	GW	ResTWR
AltWetDry			0.02 (0.01)[c]		
AdvEdu	-0.58 (0.05)[c]				-0.15 (0.10)[c]
AgEdu	0.19 (0.07)[c]				0.07 (0.10)[c]
AllClay	0.10 (0.00)[a]				
AllSand	0.03 (0.02)[b]	0.04 (0.10)[c]			
Bach	-0.52 (0.03)[b]				-0.07 (0.12)
CanalDitch	-0.04 (0.00)[a]		-0.01 (0.14)		
DieselPump	0.36 (0.05)[c]	-1.26 (0.03)[b]			
ElectricPump				0.07 (0.09)[c]	
GDD			-0.003 (0.07)[c]		
OrgMatter					-0.31 (0.05)[b]
Plevel			0.01 (0.005)[a]		
PPT			-0.02 (0.07)[c]		
Res			0.01 (0.002)[a]		
StreamRiver	0.002 (0.10)[a]		0.003 (0.01)[a]		
UsedFlowMeter		0.98 (0.01)[a]			
Pseudo R^2	0.63	0.46	0.45	0.32	0.51

Number of observations: 170. Significance values: [a] = 1%, [b] = 5%, [c] = 10%. P-values from the probit model estimates in parentheses.

The coefficient estimates for the explanatory factors of the farm, irrigation, and socioeconomic characteristics on the likelihood of irrigation source use are in Table 3. A producer with a graduate degree (AdvEdu) is 58% less likely to use natural surface water, and a producer with a bachelor's degree (Bach) is 52% less likely to use natural surface water. However, a producer with a degree in agriculture (AgEdu) is 19% more likely to use natural surface water. One possibility for the negative correlation with formal education and a positive relationship with an agricultural education is that surface water use may be viewed as a less efficient way to provide irrigation by those with a formal education. Another possibility is that a producer with an agricultural education is more willing to invest in conjunctive water management and agriculture in general than those with a formal education. A survey that collects information on producers' thoughts about irrigation efficiency or the willingness to make long-term agricultural investments might uncover what explanations are correct. An additional kilometer of canals and ditches (CanalDitch) in a county reduces the likelihood of natural surface water use by 4% while an additional kilometer of streams and rivers (StreamRiver) increases the likelihood by 0.2. An additional kilometer in canals and ditches in a county means a 1% decrease, while an additional kilometer in streams and rivers means a 0.3% increase in the use of surface water with a reservoir and tail-water recovery system. The likelihood of use of a reservoir with a tail-water recovery system alone is 15% lower if a producer has a graduate degree, but the likelihood is 7% greater if the producer has a degree related to education in agriculture. An additional percentage increase in organic matter in the soil (OrgMatter) lowers the likelihood of a reservoir with a tail-water recovery system by 31%. This finding suggests a substitution between desirable soil properties due to organic matter and the irrigation requirements of a crop.

The marginal effects associated with the peer network variables for the share of irrigation water applied that uses an irrigation source are in

Table 4. Producers with a peer using surge have a higher proportion of irrigation water from a natural surface water source (an increase of 0.48), but this proportion decreases by 0.34 if the producer is in the North Delta and by 0.40 if the producer is in the South Delta. A producer with a peer using zero-grade (PeerZeroGrade) has a lower proportion of irrigation water from a natural surface water source (a decrease of 0.24). A producer with a peer using pivot (PeerPivot) has a lower proportion of irrigation water from surface water with a reservoir alone (a decrease of 1.01), but the proportion increases by 1.25 if the producer is in the Grand Prairie and increases by 1.45 if the producer is along the Mississippi River. A producer with a peer using scientific scheduling (PeerSched) has a higher proportion of irrigation from surface water with a reservoir alone (an increase of 0.28).

Producers with a peer using computerized hole selection (PeerCHS) have a higher proportion of irrigation from surface water with a reservoir and tail-water recovery system (an increase of 0.18), but the proportion decreases by 0.46 if the producer lives near Crowley's Ridge (PeerCHS*Ridge) and decreases by 0.11 if the primary reason for the reservoir and tail-water recovery system is financial assistance (PeerCHS*ReasonFin). A producer with a peer using pivot has a higher proportion of irrigation from a reservoir with tail-water recovery (an increase of 0.53), but the proportion

Table 4. Marginal effects[1] for the peer network variables to explain the share of water applied by irrigation source.

Variable	Share_SW	Share_SWRes	Share_ SWResTWR	Share_GW	Share_ ResTWR
PeerCHS			0.18 (0.01)[a]		
PeerPLevel			-0.57 (0.00)[a]	0.04 (0.05)[b]	
PeerSurge	0.48 (0.11)[a]				
PeerPivot		-1.01 (0.13)	0.53 (0.00)[a]	0.05 (0.08)[c]	0.09 (0.11)[c]
PeerSched		0.28 (0.02)[a]			
PeerZeroGrade	-0.24 (0.08)[b]				
PeerMI					-0.48 (0.00)[a]
PeerMI*Ridge					0.62 (0.00)[a]
PeerMI*ND					0.31 (0.00)[a]
PeerCHS*Ridge			-0.46 (0.00)[a]		
PeerCHS*ReasonFin			-0.11 (0.07)[c]		
PeerSurge*ND	-0.34 (0.19)[c]				
PeerSurge*Ridge	-0.40 (0.19)[c]				
PeerPivot*GP		1.25 (0.07)[c]	-0.75 (0.00)[a]		0.25 (0.00)[a]
PeerPivot*ND			-0.53 (0.00)[a]		
PeerPivot*River		1.45 (0.04)[b]			1.23 (0.00)[a]
PeerPivot*CRP					-0.28 (0.00)[a]
Wald Chi2	62.89	190.35	396.32	$2.33*10^{7}$	154.46
LR test of independent equations: Chi squared statistics	2.60 (0.11)	0.86 (0.35)	0.99 (0.32)	11.89 (0.001)	1.16 (0.28)

Number of observations: 170. Significance values: [a] = 1%, [b] = 5%, [c] = 10%. P-values from the bivariate sample selection model estimates in parentheses. [1]The marginal effects for the peer variables that also have interaction variables assume the interaction variables are zero. For example, the marginal effect on PeerSurge in the Share_SW column assumes the variables ND and Ridge are zero. The marginal effect on PeerSurge*ND in the Share_SW column assumes that the variables PeerSurge and ND are both one.

decreases by 0.75 if the producer is in the Grand Prairie (PeerPivot*GP) and decreases by 0.53 if the producer is in the North Delta (PeerPivot*ND). This finding illustrates the diversity in irrigation approaches across the Arkansas Delta. Intensive rice production regions like the Grand Prairie and the North Delta view reservoir and tail-water recovery systems as substitutes for pivots. Other Arkansas Delta regions view pivots as complements to reservoir and tail-water recovery systems. A producer with a peer using precision leveling (PeerPLevel) or pivots has a higher proportion of irrigation from groundwater (an increase of 0.04 and 0.05, respectively).

A producer with a peer using a pivot has a higher proportion of irrigation from a reservoir supplied by a tail-water recovery system alone (an increase of 0.09), and the proportion increases by 0.25 if the producer is in the Grand Prairie (PeerPivot*GP) and increases by 1.23 if the producer lives along the Mississippi River (PeerPivot*River). The proportion decreases by 0.28, however, if the producer participates in the conservation reserve program (PeerPivot*CRP). There is a potential substitution between the conservation reserve program and the use of a reservoir with a tail-water recovery system alone. A producer with a peer using multiple inlets (PeerMI) has a lower proportion of an irrigation that uses a reservoir supplied by tail-water recovery alone (a decrease of 0.48), but the proportion increases by 0.62 if the producer lives near Crowley's Ridge (PeerMI*Ridge) and increases by 0.31 if the producer is in the North Delta (PeerMI*ND). This is additional evidence of a diversity of irrigation approaches across the Arkansas Delta, indicated here by different approaches for rice irrigation in the North Delta versus the Grand Prairie.

The marginal effects of the explanatory factors of the farm, irrigation, and socioeconomic characteristics on the share of irrigation from an irrigation source are in Table 5. For each additional growing degree day (GDD) in a county where a producer lives, the proportion of irrigation from natural surface water decreases by 0.003. The use of surge irrigation (Surge) correlates negatively with the proportion of irrigation from natural surface water by 0.18. A producer with a graduate degree has a higher proportion of irrigation (an increase of 0.84) from surface water with a reservoir alone. A farmer that lives in a more rural county, as measured by a step along the rural-urban continuum code (USDA ERS 2013), has a 0.28 higher proportion of irrigation from surface water with a reservoir alone. The use of alternate wetting and drying (AltWetDry) and end-blocking (EndBlock) increases the proportion of irrigation from surface water with a reservoir alone by 0.52 and 0.27, respectively. The use of pivots (Pivot) reduces the proportion of irrigation from surface water with a reservoir alone by 0.25.

A farmer with a graduate degree has a higher proportion of irrigation from surface water with a reservoir and tail-water recovery system by 0.27 than a farmer without a college degree. An additional kilometer of streams and rivers in a county increases the proportion of irrigation from surface water with a reservoir and tail-water recovery system by 0.01. The use of multiple inlets (MI) for rice irrigation and reservoirs (Res) increases the proportion of irrigation from surface water with a reservoir and tail-water recovery system by 0.09 and 0.14, respectively. The use of zero-grade leveling (ZeroGrade) reduces the proportion of irrigation from surface water with a reservoir and tail-water recovery system by 0.07. The use of computerized hole selection (CHS), reservoirs, and tail-water recovery systems decreases the proportion of irrigation from groundwater by 0.05, 0.13, and 0.07, respectively. The use of center pivots increases the proportion of irrigation from groundwater by 0.06. An additional kilometer of streams and rivers in a county where a producer lives lowers the proportion of irrigation from groundwater by 0.001. The use of end-blocking and zero-grade leveling influences the proportion of irrigation from reservoirs filled by a tail-water recovery system alone by 0.06 and -0.05, respectively.

Discussion and Conclusion

We are the first to consider the factors that influence the use of irrigation water sources in the LMRB, but previous studies looked at how such factors affect the use of efficient irrigation practices in other regions. For instance, studies show advanced education has a direct correlation with

Table 5. Marginal effects for the farm, irrigation, and socioeconomics variables for the share of water applied by irrigation source.

Variable	Share_SW	Share_SWRes	Share_ SWResTWR	Share_GW	Share_ ResTWR
AltWetDry		0.52 (0.27)b			
AdvEdu		0.84 (0.00)a	0.27 (0.00)s	0.11 (0.10)c	
AllClay		0.04 (0.09)c	0.02 (0.00)a		
AllSand	0.14 (0.06)c				0.03 (0.00)a
Bach	0.09 (0.05)c				
DieselPump		0.39 (0.00)a			
EndBlock		0.27 (0.17)c			0.06 (0.03)b
GDD	-0.003 (0.09)c	-0.002 (0.14)			
MI			0.09 (0.03)a		
OrgMatter		-2.54 (0.00)a			
pH>6.0		0.002 (0.01)a		0.003 (0.05)b	-0.06 (0.00)a
Pivot		-0.25 (0.13)c		0.06 (0.03)b	
Res			0.14 (0.05)a	-0.13 (0.038)a	
StreamRiver			0.01 (0.00)a	-0.001 (0.03)b	
Surge	-0.18 (0.09)b				
TWR				-0.07 (0.04)b	
ZeroGrade			-0.07 (0.03)a		-0.05 (0.03)c
Wald Chi2	63	190	396	233000	154
LR test of independent equations: Chi squared statistics	2.6 (0.12)	0.9 (0.35)	0.9 (0.32)	11.9 (0.001)	1.2 (0.28)

Number of observations: 170. Significance values: ^{a} = 1%, ^{b} = 5%, ^{c} = 10%. P-values from the bivariate sample selection model estimates in parentheses.

the use of new irrigation practices (Frisvold and Bai 2016). We find that the share of irrigation water applied from sources that involve reservoirs with natural surface water rise with greater education. Genius et al. (2014) indicate that the adoption of drip irrigation occurs more slowly on sandy soil. Our findings indicate that the use of natural surface water and surface water with a reservoir alone is more likely on sandy soil. Also, farms with sandy soil use a greater share of irrigation water from a reservoir with tail-water recovery alone.

Past studies have shown that the effectiveness of peer communication depends on how information spreads among peers, such as through the size of the peer group (Bandiera and Rasul 2006), the distance peers are from each other (Sampson and Perry 2019a;b), and whether an affirmative, neutral, or negative experience with the irrigation practice occurs in the communication (Conley and Udry 2010). The examination of the peer use of multiple irrigation practices reveals relationships not seen by looking at the producers' use of the irrigation practices themselves. For example, the use of water from a reservoir and tail-water recovery system decreases with the peer use of reservoirs only in the northern Arkansas Delta. Another example is that the share of reservoir and tail-water recovery water use increases the peer use of pivot except when in the Grand Prairie or North Delta. The findings reveal the diversity of irrigation source choice across the Arkansas Delta.

Crane-Droesch (2018) considers the role of social learning in the adoption of a soil amendment to improve fertility and shows that both the expected profitability and the associated risk transmit through social networks. This might explain why the influence of the peer use of irrigation practices differs in the use of an irrigation water source versus for the share of the water source applied. Natural surface water use increases with the peer use of a tail-water recovery system, but the share of natural surface water use increases with the peer use of surge and the peer use of pivot in certain locations. Another example is that the use of a reservoir and tail-water recovery system increases with the peer use of precision leveling, but the share of water from a reservoir and tail-water recovery system increases with the peer use of computerized hole selection. In California, Schoengold and Sunding (2014) find that if low-cost surface water is available with certainty, there is greater investment in sprinkler and drip irrigation because a producer is confident about repaying the investment loans.

In addition to the influence of social networks on the peer use of irrigation practices, the farm, irrigation, and socioeconomic characteristics also have a role in irrigation source choice. Those with a graduate degree are less likely to use natural surface water, use a larger share of surface water with a reservoir alone, use a larger share of water with a reservoir and tail-water recovery system, and use a larger share of groundwater. Although past studies have not been conclusive about the effects of education, Wheeler et al. (2010) show that as producers age, they are less likely to change farm practices during times of production uncertainty and less likely to engage in labor-intensive practices. A producer that uses pivots for irrigation uses a smaller share of surface water with a reservoir alone and uses a larger share of groundwater. A producer that uses zero-grading uses a smaller share of surface water with a reservoir alone and a smaller share of water from a reservoir filled by a tail-water recovery system alone. Green et al. (1996) show that the scale of a large farm allows for more investment in efficient irrigation practices, and this increases the likelihood of precision agriculture adoption.

An additional kilometer of streams and rivers in a county increases the likelihood of use of natural surface water and the use of surface water with a reservoir and tail-water recovery, and producers use a larger share of water with a reservoir and tail-water recovery system and use a larger share of groundwater. More sandy soil increases the likelihood of the use of natural surface water and increases the share of water from a reservoir and tail-water recovery system. Genius et al. (2014) find that farmers are slow to adopt drip irrigation on soils derived from sandy limestone than from soils of differing texture. Producers with desirable properties in the soil and high fertility are more likely to use drip irrigation while producers with low fertility soils are less likely to use drip irrigation (Shrestha and Gopalakrishnan 1993). A 1% increase in the slope steepness in California increases the likelihood of sprinkler irrigation by 0.01% and precision irrigation by 9.81%, and the likelihood of furrow irrigation decreases by 0.32% (Green et al. 1996).

Policy efforts to conserve groundwater in the LMRB include providing information and incentives on the conjunctive use of surface water with groundwater. By understanding what positively correlates with surface water use for current farmers, we may better encourage new farmers to adopt surface water and allow for the continued use of surface water by farmers that have already adopted. Extension personnel and other stakeholders can use these findings to help identify which farmers are the best candidates for the adoption of surface water for irrigation. For example, from the highlighted findings in the prior two paragraphs, stakeholders are likely to have more success with farmer's that have greater education, do not currently use pivots or zero-grade leveling, and live in counties with abundant surface water and sandy soils. Also, the peer use of several types of irrigation practices correlates with the use of surface water, but this correlation is found to depend on where the farmer is within the Arkansas Delta. Stakeholders that want to target the use of surface water should find out if the producer has peers that use a tail-water recovery system or precision leveling. However, for targeting a greater share of surface water from irrigation, the stakeholders should find out if the producers have peers that use surge valves and computerized hole selection.

The evaluation of how the practices by peers affect irrigation source choice offers insight into the diversity of irrigation within the region. The irrigation sources other than groundwater that are common are natural surface water and surface water from a reservoir and tail-water recovery system. Peer use of a tail-water recovery system increases the use of both irrigation sources. However, peer use of alternate wetting and drying is important for natural surface water use, and peer use of precision leveling is important for surface water from a reservoir and tail-water recovery system. This diversity of peer influence by irrigation practice in the Arkansas Delta reflects the large geography and the heterogeneity in the access to surface water and the depletion of groundwater over the region.

Peer use of irrigation practices correlates with farmers' irrigation source decisions, but more research could illuminate how peers have this influence on irrigation sources. A new producer survey could provide additional information about the peers who use the common irrigation practices. This information could include who the peer is (i.e., family or friend), spatial proximity of the peer to the farmer, and the type of information shared between the peers. Other explanatory factors would be worthwhile to further investigating too. Education appears to influence the use and the share of the irrigation sources, and this raises the question whether more formal education or the more specific technical information provided by stakeholders is valuable. The soil texture and acidity also play a frequent role in the sharing of water from irrigation sources, likely because these are indicators of the suitability of the land for rice.

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Appendix

Appendix A1 has a more expansive literature review than that provided in the introduction. Appendix A2 has additional tables with summary statistics and marginal effects for probit estimation of variables significant at the 15% level or above. Tables A1 and A2 have summary statistics for the dependent variables, and Table A3 has the summary statistics for the explanatory variables significant at the 10% level or below. Table A4 has the summary statistics for the other explanatory variables, significant at the 15% level or above, in the bivariate sample selection analysis for the modeling of the irrigation sources. Table A5 has the marginal effects of the probit estimation for the use of an irrigation source for all variables significant at the 15% level or above. Table A6 has the marginal effects for the explanatory variables for explaining the share of an irrigation source for all variables significant at the 15% level or above.

Appendix A1: Literature Review

We first look at the literature surrounding the influence of peer communication on irrigation choice and the role of outside influencer communication such as extension agents. Next, we look at the literature that considers the influence of the sociodemographic and environmental characteristics of the farm on irrigation choice.

The effectiveness of peer communication depends on how information spreads among peers, such as through the size of the peer group, the distance peers are from each other, and whether an affirmative, neutral, or negative experience with the irrigation practice occurs in the communication. Sampson and Perry (2019a;b) observe that a greater distance among farmers corresponds to a diminishing effect on the influence that one farmer who adopted irrigation has on the other farmer adopting irrigation. Likewise, the larger distance among farmers has a similar effect related to irrigation practice adoption (Maertens and Barrett 2013; Genius et al. 2014). Bandiera and Rasul (2006) find, that as the number of peers in the social group increases, the adoption of sunflower seeds exhibits an inverse-U shape with producers having a 0.271% likelihood to adopt with one to five peers, 0.557% likelihood to adopt with five to ten peers, and 0.300% likelihood to adopt with 10+ peers, respectively. The result indicates that an emerging number of adopters provides more encouragement to a producer to try a new technology or input than a fully established number of adopters.

A peer with good news about an input increases the likelihood of the adoption of an input, but a peer with bad news about an input often decreases the likelihood of the adoption of an input by a greater magnitude (Conley and Udry 2010). An exception to this rule is that Conley and Udry (2010) found that good news about fertilizer increases the chance of fertilizer use more than bad news about the fertilizer decreases the chance of fertilizer use. If the profitability of the technology depends on the variability in the characteristics of the potential adopters (e.g., irrigation feasibility), then the social network has a weaker influence (Tjernström 2016). The ability to learn from others is more challenging if important characteristics of the farm that determine the success of the new technology are unobservable. Crane-Droesch (2018) considers the role of social learning in the adoption of a soil amendment to improve fertility and shows that both the expected profitability and the associated risk transmit through social networks.

Outside influencer communication includes extension agents that promote alternative farming practices for the sake of reducing input costs and conserving natural resources. However, the role of extension agents in the adoption of new farming practices is negative or insignificant in some cases (Conley and Udry 2010; Ward and Pede 2014) while the role is positive in other studies (Genius et al. 2014). As the distance between the farm and an extension office increases, the extension agents spend less time at the farm. Rural farms likely receive less information from the extension personnel (Genius et al. 2014). The influence of peer interaction on input choice and farm practices is stronger than information from extension agents (Ward and Pede 2014).

The irrigation water sources and practices chosen also depend on the sociodemographics of the farm operator and the environmental characteristics of the farm. Pokhrel et al. (2018) find that as age increases, the likelihood of a cotton producer using conventional furrow irrigation rises, while the likelihood of pivot and drip does not change. As producers age, they are less likely to change farm practices during times of production uncertainty and less likely to engage in labor-intensive practices (Wheeler et al. 2010). The scale of a large farm allows for more investment in efficient irrigation practices, and this increases the likelihood of precision agriculture adoption (Green et al. 1996). Uncertainty in precipitation makes Coloradan producers more likely to adopt sprinkler systems (Schuck et al. 2005), but California producers are less likely to use precision irrigation (Schoengold and Sunding 2014).

High income from on-farm activities increases the likelihood of irrigation practice adoption, but high income from off-site activities decreases irrigation practice adoption (Wheeler et al. 2010; Frisvold and Bai 2016). As water prices increase through fuel expenses at a well, producers are more likely to use efficient irrigation practices such as sprinkler and drip but less likely to use inefficient practices such as furrow (Schoengold and Sunding 2014; Frisvold and Bai 2016). However, if low-cost surface water is available with certainty, Schoengold and Sunding (2014) find greater investment in sprinkler and drip irrigation because a producer is confident about repaying the investment loans.

The environmental characteristics (e.g., soil and slope) also can affect irrigation choices. Farmers are slow to adopt drip irrigation on soils derived from sandy limestone than from soils of differing texture (Genius et al. 2014). Other properties of the soil such as bulk density, pH, and total water stable aggregates affect the irrigation practices too. Producers with desirable properties in the soil and high fertility are more likely to use drip irrigation while producers with low fertility soils are less likely to use drip irrigation (Shrestha and Gopalakrishnan 1993). A 1% increase in the slope steepness in California increases the likelihood of drip irrigation by 0.23%, sprinkler irrigation by 0.01%, precision irrigation by 9.81%, and the likelihood of furrow irrigation decreases by 0.32% (Green et al. 1996).

Appendix A2: Table of Summary Statistics and the Marginal Effects of Explanatory Variables Significant at the 15% Level or Above

Table A1. Summary statistics for dependent variables of irrigation source choice.

Variable	Definition	Percentage
SW	=1 if use natural surface source	0.404
SWRes	=1 if use surface water stored in a reservoir alone	0.187
SWResTWR	=1 if use surface water stored in a reservoir with a tail-water recovery system	0.287
GW	=1 if use a groundwater source	0.930
ResTWR	=1 if use a reservoir filled by a tail-water recovery system alone	0.211

Number of observations: 170.

Table A2. Summary statistics for dependent variables for the share of water applied by irrigation source.

Variable	Definition	Mean	Std. Dev	10th Percentile	90th Percentile
Share_SW	Share of water applied from a natural source	0.13	0.24	0	1
Share_SWRes	Share of water applied from surface water stored in reservoir alone	0.04	0.16	0	1
Share_SWResTWR	Share of water applied from surface water stored in a reservoir with a tail-water recovery system	0.06	0.15	0	1
Share_GW	Share of water applied from groundwater	0.74	0.32	1	1
Share_ResTWR	Share of water applied from a reservoir filled by a tail-water recovery system alone	0.03	0.08	0	1

Number of observations: 170.

Table A3. Explanatory variables for irrigation source modeling.

Variable	Definition	Percentage
PeerTWR	=1 if peers* used a tail-water recovery system	0.71
PeerAltWetDry	=1 if peers used alternate wetting and drying for rice irrigation	0.35
PeerCHS	=1 peers used computerized hole selection	0.56
PeerSurge	=1 if peers used surge irrigation	0.36
PeerPlevel	=1 if peers used precision leveling	0.90
PeerRes	=1 if peers used storage reservoir	0.65
PeerEndBlock	=1 if peers used end blocking, cutback irrigation, or furrow diking in irrigation	0.55
PeerSched	=1 if peers used scientific scheduling	0.53
PeerPivot	=1 if peers used center pivot	0.66
PeerMI	=1 if used multiple inlets for rice irrigation	0.70
PeerZeroGrade	=1 if peers used zero grade leveling	0.75

*Peers include family members, friends, or neighbors using a practice within the past 10 years.

Farm, irrigation, and socioeconomic characteristics

Variable	Definition	Percentage
AltWetDry	=1 if use alternate wetting and drying for rice irrigation on farm	0.05
AdvEdu	= 1 if producer has a graduate degree	0.09
Bach	= 1 if producer has a Bachelor's degree	0.44
CHS	=1 if use computerized hole selection on farm	0.35
DieselPump	=1 if use diesel pump on farm	0.91
ElectricPump	=1 if use electric pump on farm	0.88
EndBlock	=1 if use end-blocking, cutback irrigation, or furrow diking in irrigation	0.32
GP	=1 if county is in the Grand Prairie (i.e., Arkansas, Lonoke, Prairie, Pulaski, and White counties)	0.19
MI	=1 if use multiple inlets for rice irrigation on farm	0.27
ND	=1 if county is in the northern Arkansas Delta (i.e., Independence, Jackson, Lawrence, Monroe, Randolph, and Woodruff counties)	0.12
Pivot	=1 if use center pivot on farm	0.39
Plevel	=1 if precision leveling on farm	0.84
ReasonFin	=1 if primary reason for tail-water recovery system or reservoir was financial assistance	0.06
Ridge	=1 if county is in Crowley's Ridge (i.e., Clay, Craighead, Cross, Greene, Lee, Poinsett, and St. Francis counties)	0.32
River	=1 if county is along Mississippi River (i.e., Chicot, Crittenden, Desha, Mississippi, and Phillips counties)	0.23
Res	=1 if use reservoir on farm	0.38
Sched	=1 if use scientific scheduling on farm	0.05
SD	=1 if county is in the South Delta (i.e., Ashley, Drew, Jefferson, and Lincoln counties)	0.07
Surge	=1 if use surge irrigation on farm	0.39
TWR	=1 if use tail-water recovery system on farm	0.49
UsedFlowMeter	= 1 if flowmeter used	0.38
ZeroGrade	=1 if use zero grade leveling on farm	0.37

(Table A3 continued. Explanatory variables for irrigation source modeling.)

Variable	Definition	Mean	Std Dev.
AgEdu	=1 if holds an agriculture related degree	0.59	0.49
AllClay	Percent of land in the producer's county of residence with a clay and clay loam component in the soil	15.11	17.14
AllSand	Percent of land in the producer's county of residence with a fine sand, fine sandy loam, sand, sandy clay, sandy clay loam, sandy loam, and very fine sandy loam	9.24	7.65
AWS	Root zone between 0 to 150 centimeters available water storage (cm)	23.32	2.77
CanalDitch	Kilometer of canals and ditches in the county of the producer's residence	36.81	31.03
GDD	Average degree days between 283.15 and 304.82 Kelvin between 2005 and 2015 (degrees*days)	654,674	33,073
OrgMatter	Percent of organic matter in the producer's county of residence to a depth of 150 cm	1.6	0.24
pH>6.0	Percent of land in the county of the producer's residence with a pH greater than 6.0	24.27	16.86
PPT	Average growing season precipitation between 2005 and 2015 (cm)	68.28	11.61
RUCC2013	Rural-Urban Continuum code of site in 2013	5.12	2.07
StreamRiver	Kilometer of streams and rivers in the county of the producer's residence	137.30	70.78

Table A4. Additional explanatory variables for irrigation source modeling.

Variable	Definition	Percentage	
PeerTWR*ND	= 1 if peers^ used a tail-water recovery system in the northern Arkansas Delta region	0.09	
PeerTWR*CHS	= 1 if peers used a tail-water recovery and computerized hole selection	0.26	
PeerSurge*CHS	=1 if peers used surge irrigation and computerized hole selection	0.17	
PeerSurge*GP	=1 if peers used surge irrigation in the Grand Prairie region	0.05	
PeerCHS*SD	=1 if peers used computerized hole selection in the South Delta region	0.03	
PeerEndBlock*CRP	= 1 if peers used end blocking and participate in the conservation reserve program	0.28	
PeerEndBlock*EQIP	= 1 if peers used end blocking and participates in an environmental quality incentive program	0.35	
PeerEndBlock*ND	= 1 if peers used end blocking in the northern Arkansas Delta region	0.09	
PeerZeroGrade*GP	= 1 if peers used zero grade leveling in the Grand Prairie region	0.14	
PeerRes*FinReason	= 1 if peers used a reservoir and federal storage	0.24	
^Peers include family members, friends, or neighbors using an irrigation practice within the past 10 years.			
Farm and irrigation characteristics			
IrrCotton	= 1 if grows irrigated cotton	0.14	
ExpCorn	= 1 if corn yield expected in bushels/acre	102.19	
DepthIncrease	=1 if water tables have increased in height over past five years	0.12	
		Mean	**Std Dev.**
FineSand	Percent of land in the producer's county of residence with a fine sand	0.21	0.69
Socioeconomic characteristics			
IncomeNA	Net income not reported	0.24	0.43
IncomeHigh	Net income > $200,000	0.13	0.34

Table A5. Marginal effects from probit estimation: All variables significant at or above 15th percentile.

Variable	SW	SWRes	SWResTWR	GW	ResTWR
AltWetDry	0.09 (0.14)	0.01 (0.02)			0.02 (0.02)
CHS	-0.17 (0.18)	0.001 (0.02)	0.008 (0.66)	0.01 (0.01)	-0.003 (0.01)
EndBlock	-0.01 (0.05)	-0.01 (0.02)	0.22 (0.54)	-0.01 (0.01)	-0.01 (0.01)
ExpCorn			0.0002 (0.50)		
IncomeNA	-0.11 (0.27)				0.07 (0.16)
IncomeHigh	0.001 (0.99)				0.07 (0.19)
DepthIncrease			0.13 (0.16)		
MI	0.03 (0.06)	-0.04 (0.04)	-0.63 (0.58)	0.001 (0.01)	0.003 (0.01)
PeerRes			0.12 (0.16)		
PeerCHS	0.15 (0.16)				
PeerSched					-0.04 (0.21)
PeerTWR		0.06 (0.21)			
PeerTWR*ND	0.28 (0.17)				
PeerTWR*CHS	-0.16 (0.15)				
PeerSurge*CHS		-0.06 (0.51)			
PeerCHS*SD		0.14 (0.15)			
PeerEndBlock*CRP				0.04 (0.26)	
PeerEndBlock*EQIP				-0.05 (0.21)	
Pivot	-0.03 (0.06)	0.02 (0.03)	0.28 (0.82)	0.01 (0.01)	-0.02 (0.02)
Plevel	-0.05 (0.07)	0.03 (0.03)		0.01 (0.01)	0.001 (0.01)
Res	-0.05 (0.07)	0.04 (0.04)		-0.001 (0.01)	0.02 (0.02)
Sched	-0.05 (0.15)		-1.72 (1.46)		0.01 (0.02)
Surge	0.07 (0.08)	0.03 (0.03)	-0.03 (0.72)	-0.004 (0.01)	-0.003 (0.01)
TWR	0.08 (0.09)	0.01 (0.02)		0.004 (0.01)	0.002 (0.01)
ZeroGrade	0.05 (0.06)	0.01 (0.02)	-0.43 (0.65)	-0.002 (0.01)	0.01 (0.01)

Table A6. Marginal effects from bivariate sample selection: All variables significant at or above 15th percentile.

Variable	SW	SWRes	SWResTWR	GW	ResTWR
AltWetDry	-0.05 (0.12)		-0.02 (0.15)	-0.01 (0.07)	-0.09 (0.07)
CHS	-0.01 (0.15)	-0.23 (0.28)	0.03 (0.04)		
EndBlock	0.11 (0.06)		-0.06 (0.12)	-0.04 (0.03)	
IrrCotton	-0.001 (0.24)				
ExpCorn	-0.002 (0.25)	0.002 (0.33)	-0.003 (0.31)	-0.01 (0.50)	
DepthIncrease			0.03 (0.32)		
IncomeNA	-0.04 (0.66)				
IncomeMid				-1.57 (0.63)	-0.04 (0.40)
FineSand	0.08 (0.17)			2.40 (0.37)	
MI	-0.06 (0.06)	-0.27 (0.56)		-0.01 (0.03)	0.04 (0.03)
PeerZeroGrade*GP	-0.09 (0.28)				
PeerRes*FinReason	-0.08 (0.16)				
PeerSurge*GP					-0.03 (0.47)
PeerEndBlock*ND					-0.03 (0.41)
Pivot	-0.11 (0.08)		-0.07 (0.05)		
Plevel	-0.02 (0.09)	-0.33 (0.45)	-0.03 (0.18)	0.65 (0.03)	
Res	-0.12 (0.08)	-0.35 (0.41)			
Sched	-0.01 (0.16)	-0.07 (0.13)	0.02 (0.10)	0.03 (0.07)	
Surge		-0.21 (0.24)	-0.05 (0.21)	0.04 (0.04)	
TWR	-0.04 (0.11)		-0.13 (0.17)		
ZeroGrade	-0.04 (0.07)	-0.19 (0.21)		-0.06 (3.18)	