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Drivers of on-farm performance of irrigation water management practices: Empirical evidence from eastern Arkansas

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Abstract:

Unsustainable agricultural practices are putting a strain on freshwater supplies in many parts of the world. More efficient irrigation techniques are going to be critical to feed a growing population. Data from the 2016 Arkansas Irrigation Survey was used to assess the adoption of three Irrigation Water Management (IWM) practices: multiple inlet rice irrigation, tailwater recovery, and storage reservoirs. Results indicate that these practices do not always lead to reported pumping time reductions, a proxy for water use savings. Large variations in pumping time reduction are observed across producers for all three practices. A Tobit model was used to examine the relationship between pumping time reduction and a set of producer, farm, and water supply characteristics. Operators that owned their land had a more significant reduction in pumping time when using tailwater recovery systems and storage reservoirs than those who did not. Land ownership had no discernible influence on pumping time reduction for multiple inlet rice irrigation. More formal education and years of farming experience both had a negative relationship with pumping time reduction for multiple inlet irrigation. Users of tailwater recovery systems achieved sizeable pumping time reductions when faced with a declining groundwater table compared to those who implement multiple inlet irrigation. This reduction in pumping time is consistent with the role of on-farm reservoirs as an infrastructure-based solution to convert groundwater to surface water. Counter to expectations, having an agriculture-related formal education or flow meters did not influence reported pumping time savings. By providing empirical evidence on how different factors can affect the effectiveness of IWM practices, findings from this paper provide insight for IWM implementation programs.

1. Introduction

Water scarcity poses a major risk to current agricultural practices in many regions of the world. Food production is strained by increased demand and decreases in water supply in places such as Australia, southeast Asia, and northern Africa (Huang, Wang, and Li 2017; Wood, Wang, and Bethune 2007; Alauddin and Sarker 2014). Producers in southern and midwestern United States are facing declining water tables in the main aquifers used for irrigation (Czarnecki, 2010; Omer et al., 2018; Pfeiffer and Lin, 2014). Climate change could potentially intensify these water scarcity issues with more volatile hydrologic conditions, increased evapotranspiration, and an increase in both the frequency and severity of droughts, which will especially affect arid climates (Evans et al. 2012; Funk and Brown 2009). More efficient use of water for food production is necessary to feed a growing population. Declining aquifer levels in the United States Mid-south require innovative irrigation solutions, especially for water intensive crops such as rice and corn.

Various irrigation technologies and irrigation water management (IWM) practices have shown promise to decrease water use. Multiple Inlet Rice Irrigation (MIRI) is the practice of using lay-flat pipe to distribute water to individual rice paddies in contour and precision graded flood irrigated fields. Simulations run by Yang et al. (2012) showed conversion to MIRI from cascade flood irrigation for producers in South Texas could lead to a water saving of about 10 cm per application. Farm level comparisons from Arkansas report a reduction in water use of 24% using MIRI over conventional cascade flooding (Vories et al., 2005). Data from Mississippi indicate that combing multiple-inlet rice irrigation with intermittent flooding could lead to an additional 30% reduction in water use (Massey et al., 2014). On-farm storage reservoirs and tailwater recovery systems are another strategy producers are implementing to decrease consumptive water use. Using a water budget, Omer et al. (2018) projected that the amount of groundwater withdrawal offset by surface water irrigation and seepage entailed by the 180 tailwater recovery systems installed in the Mississippi Delta area could account for 15% of the annual groundwater deficit in the lower Mississippi River Alluvial Valley (Barlow and Clark, 2011). Yang et al. (2012) also analyzed tailwater recovery and reservoirs, and showed the implementation of such systems could result in a potential water savings of 3 cm per application. Other technologies such as sprinkler irrigation and precision leveling have also shown promise to decrease consumptive water use (Henry et al., 2016; Wood et al., 2007). These technologies can be implemented on their own or in unison to make agricultural production more sustainable.

Most existing studies analyze factors that influence the adoption of irrigation technologies and IWM practices (Caswell and Zilberman 1986; Green et al. 1996; Moreno and Sunding 2005; Huang et al. 2017). A smaller set of studies has analyzed the effectiveness of those technologies or practices after adoption. Most of these studies used data from experimental fields or simulation models and assumed parameters (Wood et al. 2007; Yang et al. 2012; Omer et al. 2018). The effectiveness of irrigation technologies and best management practices can vary greatly from experiment fields, where growth conditions and the operation of irrigation techniques are controlled by researchers, to producers’ fields, where all elements can vary significantly due to weather and differences in farming ability. It is important to use data that reflect the actual irrigation behavior of producers. This study uses a survey to ask producers how using these practices have affected their pumping times. We assumed that pumping time correlated with the amount of irrigation water applied. Pumping time also determines a large part of the energy used in irrigation (Martin et al., 2011). A reduction in pumping time can incentivize producers to adopt an irrigation technology or best management practice to attain energy cost savings.

This study is among the few that link the on-farm performance of IWM practices to a set of factors such as socioeconomic dynamics and characteristics of the farm and water supply. Pfeiffer and Lin (2014) is among the few studies that use actual groundwater extraction data at points of groundwater diversion. However, in their analysis of the effects of a conversion from conventional center pivots to low-energy precision application nozzles on groundwater extraction, only a few factors (e.g., field size, climate variables) were included. Important factors such as the characteristics of producers were not included. Huang et al. (2017) also used data collected from producers in China; however, they grouped multiple irrigation technologies and best management practices together and did not analyze the effect of individual technology or practice. By providing empirical evidence on how different factors influence IWM practices, findings from this paper provide useful advice for extension agents who promote IWM practices to improve irrigation performance. The specific objectives of this study were:

1. To analyze the perceived effects that irrigation practices have at the farm level;
2. To link the on-farm perception of irrigation conservation to a set of socioeconomic factors, characteristics of the farm, and water resources;

The rest of the paper is organized as follows. The next section introduces the study setting. Section 3 describes the IWM practices analyzed in the study and their use in Arkansas. Section 4 details the methods of statistical analysis and the dataset used. Section 5 reports the results and discussion of the analysis, and Section 6 provides conclusions and potential policy implications.

2. Study Setting

The agriculture sector in Arkansas contributes a higher percentage of gross domestic product than any other state in the United States, totaling 8.14 billion dollars in 2010 (Reba et al., 2013). The main crops are soybean, rice, corn, and cotton. Arkansas ranks in the top twenty nationally for these four crops and leads the nation in rice production (USDA 2018). The mild, sub humid climate and fertile soils of Eastern Arkansas make it ideal for agriculture. Many growing regions have soils with a shallow clay layer that holds water near the surface and prevents deep percolation; optimal conditions for rice production (Gates, 2005). The region receives ample rain, but the majority of it occurs during the non-growing season (Reba et al., 2013). In addition, evapotranspiration exceeds precipitation in the state six months out of the year on average, especially in the hot and humid summer months (Arkansas Natural Resource Commission 2014). Irrigation water demand is highest in July and August when precipitation frequencies and amounts are lowest and inadequate to meet crop water demand. Environmental factors and growing requirements for the main crops have led to nearly all of the farmland in Arkansas being irrigated, accounting for 7% of all irrigated cropland nationally (United States Geological Survey 2017).

The main source for irrigation water in eastern Arkansas is groundwater pumped from the Mississippi River Valley Alluvial Aquifer (MRVAA). The aquifer accounts for 95% of the total groundwater use for the state, and agriculture accounts for 98% of that total (Battreal, 2016). Since record-keeping began in the early 1900s, water withdrawal from the aquifer has been steadily increasing (Omer et al. 2018; Czarnecki 2010; Arkansas Natural Resource Commission 2014). Battreal (2016) found that in 2015 more than twice the estimated sustainable yield was pumped from the aquifer. Nearly two-thirds (63.5%) of the 394 alluvial aquifer wells monitored from 2006 to 2016 had a decline in the static water level, with an average decline of 0.52 meters (Battreal, 2016). It is estimated that if current agricultural practices continue, there will be an annual statewide groundwater gap of more than 10.1 billion cubic meters by 2050, primarily affecting eastern Arkansas (Arkansas Natural Resources Commission 2014). The three main growing regions in Eastern Arkansas are the Delta, White River, and Grand Prairie. The Delta zone typically has the most reliable water supply of the three, whereas the White River zone has the least reliable. The 2014 Arkansas Water Plan Update has identified two critical initiatives to address groundwater shortages (Arkansas Natural Resources Commission 2014) :

1. Improved on-farm irrigation efficiency through conservation efforts
2. The conversion of groundwater to public surface water infrastructure development and on-farm storage

This study focuses on IWM practices that address both initiatives.

3. Irrigation Water Management Practices Studied

Although the 2016 Arkansas Irrigation Survey collected information on a number of IWM practices, this study focuses on only two of the most commonly used practices in the study area. The two IWM practices studied entail the largest sample sizes in statistical analysis because many producers have reported a reduction in pumping time for these. The first practice is multiple inlet rice irrigation (MIRI). Traditional rice production involves creating paddies or levees on fields with very little grade so that a flood depth of about 10 cm can be maintained. A gate is placed between each paddy such that water cascades from paddy to paddy (Vories et al. 2005). MIRI is the practice of placing lay-flat pipe throughout a field and inserting holes in the pipe which evenly disperses water across the entire field, flooding all paddies simultaneously

(Massey et al., 2018). The main improvement in irrigation efficiency is derived from the ability to capture rainfall events by maintaining storage capacity in the paddies. This storage results in a shallower flood and less deep percolation and seepage through the outside levees (Vories et al. 2005). The ability to establish a quicker and more precise flood as compared to cascade flood irrigation is another factor which makes MIRI a more efficient irrigation method (Massey et al., 2018). Computer software, mobile apps, and online web tools are available to aid producers in the sizing and implementing of MIRI (Henry et al. 2018). Although lay flat MIRI was only introduced in 1991, some producers report having used multiple inlet irrigation before this time. Producers claiming to have used MIRI before 1991 would have used canal-based forms of multiple inlet rice irrigation or multiple inlet sources provided by pipeline installations where multiple wells or pumps could supply water to more than one location in a field. Because these forms of multiple inlet irrigation were not intended to be included in this study, producers who reported using MIRI before 1991 were removed from regression analysis. In Arkansas, producers began using multiple inlet rice irrigation in the late 1990s. The 2016 Arkansas Irrigation Survey shows that since the early 2000s its use rate has grown rapidly.

The second IWM practice the study analyzes is the combined use of tailwater recovery systems and on-farm storage reservoirs. Tailwater recovery systems include a tailwater pit at the lowest elevation in a field. A pump and pipeline are installed so that tailwater and runoff collected by the pit can be returned to the inlet of the field for the next irrigation event. Irrigation storage reservoirs are large impoundments where water from either a series of tailwater pits or conveyance canals is used to collect and deliver water to the reservoir. A tailwater recovery system is often coupled with on-farm reservoirs, so they are analyzed together in the study. Tailwater recovery and storage reservoirs can be used for any irrigation system which has significant runoff. Potential benefits of tailwater recovery systems include reduced groundwater dependence, reduced energy costs from pumping, greater control of water supply for irrigation, reduced off-farm impacts on water quality from runoff, and the potential to recharge aquifers (Henry et al., 2018; Reba et al., 2017). Water recovery and storage practices have been in use for many years. The 2016 Arkansas Irrigation Survey shows a sharp increase in their implementation around 2000. The main drawbacks of tailwater recovery systems and on-farm reservoirs are their capital cost and the need to take land out of production (Yaeger et al., 2018). Agencies such as Natural Resources Conservation Service and local water districts have financial assistance programs for the implementation of a surface water storage and reuse system (C. Henry et al., 2018).

In Arkansas, irrigation pumps are generally not metered, and if they are metered the annual total values are not used to report water use. Thus, Arkansas irrigators have no standard for which to report water use savings from conservation adoption. To assess the possible impact of conservation practices, producers can be asked about the reduction in pumping time before and after different conservation practices were adopted. Most producers have a good knowledge of their pumping time and are likely to provide objective responses. For MIRI, reductions in pumping time should serve as a good surrogate to a reduction in water use from aquifers. However, tailwater recovery systems and storage reservoirs are often implemented because well pumps are failing. In addition, surface pumps are often much higher capacity than well pumps because considerably less energy is required to move water and the irrigation system is engineered to meet crop water demand at installation. Because of these factors, a reduction in pumping time is generally, but not always, anticipated from a conversion to a tailwater recovery system or storage reservoir. While reductions in pumping time can indicate improved on-farm performance, it does not necessarily correlate with decreased water use for tailwater recovery or irrigation storage reservoirs.

4. Methods

The study uses data from the 2016 Arkansas Irrigation Survey, conducted by researchers from the University of Arkansas and Mississippi State University (CGH). Sample producers in Arkansas are drawn from the Arkansas Natural Resources Commission (ANRC) water user database and Dun & Bradstreet's list of all commercial crop growers. Telephone interviews were conducted to determine candidate producers. Although a total of 3,712 producers were contacted, only 624 were eligible to complete the survey. The final sample includes 231 producers who completed the survey. Assuming a population size of 4,212 irrigators in Arkansas, a confidence interval of 95%, and a response distribution of 50%, the margin of error was calculated to be 6.27% for those that completed the survey. The survey collected information on most IWM practices that are used by Arkansas producers. For a subset of the IWM practices, producers were asked, "For each of the following changes you've made to irrigation, by what percent did pumping time decrease (if any) as a result of the change?" A change indicates an IWM practice is used. Answers are used to construct the pumping time reduction variable. In the survey, producers were asked which category best described their 2014 household income from all sources before taxes. Answers are coded in the same set of intervals of income as in the Census of Agriculture: Less than \$10,000, \$10,000 to \$15,000, \$20,000 to \$25,000, \$25,000 to \$35,000, \$35,000 to \$50,000, \$50,000 to \$75,000. The survey also contains information that allows us to construct variables to measure characteristics of producers, farms, on-farm water supply, and IWM practices.

Multivariate statistical analysis determines the effect of a factor on pumping time reduction while controlling for influence of other factors. The objective of the multivariate statistical analysis is to analyze which factors influence the rate of pumping time reduction due to the use of an IWM practice. Let y_{ik} denote the level of pumping time reduction of producer i when IWM practice k is used. The simple approach is to estimate the following equation:

$$y_{ik} = \mathbf{x}'_{ik}\boldsymbol{\beta} + \varepsilon_{ik} \tag{1}$$

The vector $\mathbf{x}_{ik}$ contains a set of explanatory variables. Several dummy variables are used to indicate whether a producer has attained a bachelor's degree or above, his/her formal education is related to agriculture, and the producer is a landowner instead of an operator. Continuous variables include years of farming experience, household 2014 pre-tax income, and the percentage of household income generated from farming work. Total irrigated area and the share of irrigated area allocated to rice production reflect farm size and crop mix. The percentage of land that is gravity irrigated can indicate if other technologies, such as sprinkler irrigation, are being used. The share of irrigation water supplied by groundwater and whether depth-to-groundwater has increased in the last five years indicate farm-level water supply characteristics. The survey also asked whether flow meters are installed on well and the length of time any IWM practice has been in use. For tailwater recovery and storage reservoir systems, the size, area, and depth of the largest reservoir on a producer's farm are included. Two dummy variables indicate a producer's location in one of the three major rice production zones in Arkansas (Tseng et al. 2013): one for the Upper White River Valley of Arkansas (White River) and the other for the Delta zone. The error term, ε_{ik}, is assumed to follow a normal distribution with a mean of zero.

The vector of parameters, $\boldsymbol{\beta}$, in equation (1) measures the effect of $\mathbf{x}_{ik}$ on y_{ik}. The method of ordinary least squares (OLS) can be used to estimate $\boldsymbol{\beta}$, where the sum of squared prediction errors is minimized. However, this approach may generate biased estimates because the values of a pumping time reduction are only observed for a selected sample of producers: those that have used the k^{th} IWM practice. The correct model for the rate of pumping time reduction consists of the selection equation and the outcome equation. The selection equation is

$$P_{ik} = \mathbf{1}(\mathbf{z}'_{ik}\boldsymbol{\alpha} + u_{ik} > 0), \tag{2}$$

where $\mathbf{1}(\cdot)$ is an indicator function. The binary variable P_{ik} equals one if producer i uses IWM practice k, and if the net benefit, represented by $\mathbf{z}'_{ik}\boldsymbol{\alpha} + u_{ik}$, is positive. The vector $\mathbf{z}_{ik}$ contains factors that may influence costs and/or benefits of using IWM practice k. The outcome equation is a modified version of equation (1):

$$y_{ik} = \begin{cases} \mathbf{x}'_{ik}\boldsymbol{\beta} + \varepsilon_{ik} & \text{if } P_{ik} = 1 \\ - & \text{if } P_{ik} = 0 \end{cases} . \tag{3}$$

Using equations (2) and (3), it can be shown that

$$E[\varepsilon_{ik}|P_{ik} = 1] = \sigma_{u\varepsilon}[\phi(\mathbf{z}'_{ik}\boldsymbol{\alpha})/\Phi(\mathbf{z}'_{ik}\boldsymbol{\alpha})], \tag{4}$$

where $\sigma_{u\varepsilon}$ is the covariance between the error term in (2), u_{ik}, and that in equation (3), ε_{ik}. The function $\phi(\cdot)$ is the standard normal probability density function, and $\Phi(\cdot)$ is the standard normal cumulative density function. The term $\lambda(\mathbf{z}'_{ik}\boldsymbol{\alpha}) = \phi(\mathbf{z}'_{ik}\boldsymbol{\alpha})/\Phi(\mathbf{z}'_{ik}\boldsymbol{\alpha})$ is often called the Inverse Mills Ratio (IMR) and accounts for selection bias. Equation (4) indicates that when u_{ik} and ε_{ik} are correlated, ($\sigma_{u\varepsilon} \neq 0$), the mean of ε_{ik} is not zero. Estimating equation (1) would produce biased estimates of $\boldsymbol{\beta}$ because the "regressor" $\lambda(\mathbf{z}'_{ik}\boldsymbol{\alpha})$ was omitted by mistake. Heckman's two-step procedure is commonly used to correct for such sample selection bias (Heckman, 1979). This procedure augments equation (1) by including an estimate of the IMR:

$$y_{ik} = \mathbf{x}'_{ik}\boldsymbol{\beta} + \sigma_{u\varepsilon}\lambda(\mathbf{z}'_{ik}\hat{\boldsymbol{\alpha}}) + v_{ik}, \tag{5}$$

where v_{ik} is an error term. The vector $\hat{\boldsymbol{\alpha}}$ is obtained by a Probit regression of P_{ik} on $\mathbf{z}_{ik}$. The Probit model assumes the error term, u_{ik}, is normally distributed. With the normal distributional assumption,

$$\Pr(P_{ik} = 1) = \Pr(\mathbf{z}'_{ik}\boldsymbol{\alpha} + u_{ik} > 0) = \Pr(u_{ik} > -\mathbf{z}'_{ik}\boldsymbol{\alpha}) = \Phi(\mathbf{z}'_{ik}\boldsymbol{\alpha}). \tag{6}$$

Using (5), the log of the likelihood function of observing all the data points is

$$\ln L = \Sigma_i\left[P_{ik}\ln\Phi(\mathbf{z}'_{ik}\boldsymbol{\alpha}) + (1 - P_{ik})\ln(1 - \Phi(\mathbf{z}'_{ik}\boldsymbol{\alpha}))\right]. \tag{7}$$

The method of maximum likelihood estimation (MLE) is used to obtain $\boldsymbol{\alpha}$ that maximizes ln$L$. The IMR for using a practice is then imputed for each observation.

The vectors $\mathbf{z}_{ik}$ and $\mathbf{x}_{ik}$ have common variables that both affect IWM implementation and its success in reducing pumping time. For equation (4) to be identified, the vector $\mathbf{z}_{ik}$ should contain at least one variable that is not in $\mathbf{x}_{ik}$ and can be used as the exclusion restriction. Otherwise, the term $\lambda(\mathbf{z}'_{ik}\hat{\boldsymbol{\alpha}})$ would be highly collinear with $\mathbf{x}_{ik}$. Four variables are included in $\mathbf{z}_{ik}$ as the exclusion restrictions. All four variables could influence a producer's decision to use an IWM practice, but are not likely to affect the change in pumping time due to the use of the IWM practice. The variables include: a dummy variable indicating whether a producer is aware of a state tax credits program that allows producers to claim up to $9,000 tax credit for conversions to surface water or land leveling, a dummy variable that equals one if a producer is concerned water shortage may occur in the state, the percentage of producers in the county that have participated in any federal, state, or local conservation programs in the last five years, and whether anyone in a producer's close network (family members, friends, or neighbors) has used the same IWM practice.

One additional source of sample selection bias is that pumping time reduction is only observed for producers who know how much pumping time has changed as a result of using the practice. The IMR for knowing the pumping time reduction is imputed from the estimation results of another Probit model where the dependent variable is the dummy variable that equals one if a producer reported a number for pumping time reduction during the survey. The variable "whether water flow meters are installed on wells" is used as the exclusion restriction variable.

Another consideration is that the dependent variable, the level of pumping time reduction, is bounded between 0% and 100%, with a higher percentage indicating a larger reduction. The model can be represented as

$$y_{ik}^* = \mathbf{x}'_{ik}\boldsymbol{\delta} + e_{ik}$$
$$y_{ik} = \begin{cases} 0 & \text{if } y_{ik}^* \leq 0 \\ \mathbf{x}'_{ik}\boldsymbol{\delta} + e_{ik} & \text{if } 0 < y_{ik}^* < 1 \\ 1 & \text{if } y_{ik}^* \geq 1, \end{cases} \tag{8}$$

where y_{ik}^* is an unobserved latent variable and the error term, e_{ik}, is assumed to be normally distributed with a mean of zero and a variance of σ^2. A two-limit Tobit model (Tobin 1958; Maddala 1983) can be used to estimate the parameters vector $\boldsymbol{\delta}$ by maximizing the following log likelihood function:

$$\begin{aligned} \ln L_{\text{Tobit}} = \Sigma\{ \quad & \mathbf{1}(y_{ik} = 0)\cdot\ln(1 - \Phi(\mathbf{x}'_{ik}\boldsymbol{\delta}/\sigma)) \\ & + \mathbf{1}(0 < y_{ik} < 1)\cdot\ln[(1/\sigma)\phi((y_{ik} - \mathbf{x}'_{ik}\boldsymbol{\delta})/\sigma))] \\ & + \mathbf{1}(y_{ik} = 1)\cdot\ln[1 - \Phi((1 - \mathbf{x}'_{ik}\boldsymbol{\delta})/\sigma)]\}, \end{aligned} \tag{9}$$

where $\Pr(y_{ik}^* \leq 0) = 1 - \Phi(\mathbf{x}'_{ik}\boldsymbol{\delta}/\sigma)$ and $\Pr(y_{ik}^* \geq 1) = 1 - \Phi((1 - \mathbf{x}'_{ik}\boldsymbol{\delta})/\sigma)$. To correct for the sample section bias, the two IMRs described above are also added as explanatory variables.

Although descriptive analyses (Figure a1, a2 and Table 3) provide some insights into the relationship between pumping time reduction and relevant factors, only the correlation or a nonlinear relationship between two factors can be revealed. In some cases, this may be misleading. For example, the positive relationship between the sizes of irrigated area and pumping time reduction among producers that use MIRI (Figure a1, Panel d) may arise from the influence of other factors such as household income. Therefore, multivariate analysis is needed to control for confounding variables. The relationships observed in descriptive analysis (Figures a1 and a2, Table 3) are used to guide the specifications of the Tobit model. In particular, for those continuous factors that exhibit a nonlinear relationship with pumping time reduction, a squared term is added. Estimated coefficients of the Tobit model that include the squared terms are reported (Table a1). Not all squared terms have statistically significant coefficients. For the sake of parameter parsimony, in the final specifications reported (Table 4), we have removed the squared terms that do not have statistically significant coefficients. For most continuous variables, the original variable will be highly correlated with its square term. This may cause a multicollinearity problem in the estimation where the high correlations among two or more explanatory variables would result in large standard errors (imprecise estimates). Upon adding both the original and the squared terms of the same variable, multicollinearity is recognized in our explanatory variables, $\mathbf{x}_{ik}$. One solution is to use standardized values of a variable, which are obtained by first subtracting the mean of the variable from its original values, then dividing the deviation from mean by its standard deviation. Except for the variable that measures the size of the largest reservoir on-farm, using standardized values removes the multicollinearity problem in our data. In the final specifications (Table 4), variables that may have nonlinear relationships with pumping time reduction are first standardized and then squared. The variable that measures share of gravity irrigated land is removed because its values do not vary much.

The estimation results of the final specifications used for the Tobit models are reported (Table 4). Note that $\boldsymbol{\delta}$ only measure the effects of explanatory variables, $\mathbf{x}_{ik}$, on the unobserved latent variable y_{ik}^* in equation (8). More interests may lie in the effects of $\mathbf{x}_{ik}$ on y_{ik}, the pumping time reduction observed in the data (reported by producers). Therefore, for most variables, Table 4 reports the marginal effects of an explanatory variable on y_{ik} in equation (8), computed using the estimation results of the Tobit models. For variables that also have squared terms, their estimated coefficients are reported (Table 4). However, the coefficients of standardized versions of variables and their squared terms do not have straightforward interpretation. To facilitate interpretation, the marginal effects of these variables are plotted (Figure 3 and 4).

5. Results and Discussion

The 2016 Arkansas Irrigation survey reports the use rates of multiple inlet rice irrigation, tailwater recovery and irrigation storage reservoir systems and the effects of these practices (Table 1 and 2). Many producers (42%) used multiple inlet rice irrigation in 2015, but not every producer achieved a lower pumping time. Although most producers that used multiple inlet rice irrigation (71%) noticed a positive decrease in pumping time, 10% did not notice any decrease. In addition, a portion of the producers (19%) was unsure of the effect on pumping time (Table 1). The average reduction in pumping time for producers that noticed zero or positive decrease in pumping time was 20.9%. Of producers that reported a positive decrease in pumping time, the mean reduction was 24% (Table 2). This is consistent with the water savings of 25% often reported in the media (Henry 2016). The data also show there are large variations in the performance of multiple inlet irrigation across producers. The standard deviation of 13% is large compared to the mean, and the reduction can range from as little as 1% to as large as 75%. About half (50.2%) of sample producers were using tailwater recovery or on-farm storage reservoirs in 2015 (Table 1). Compared to multiple inlet rice irrigation, a smaller share of producers reported a positive decrease in their pumping times (56% versus 71%). A larger share of producers (29%) reported no decrease, and a similar percentage (15%) was unsure of the effect on pumping time. Among producers that reported zero or positive decrease in pumping time, the average reduction was about 19.1% (Table 2). The average increases to a 29% reduction for producers that reported a positive decrease in pumping time. However, the performance of tailwater recovery and reservoir systems also exhibits large variations. The standard deviation is about half of the mean, and the level of pumping time reduction spans from 10% to 62.5%.

Table 1. Reported effects of IWM practices on pumping time, number of producers

Irrigation water management practice		Responses by reported effects on pumping time		
	(1). N users	(2). Don’t know	(3). Zero decrease	(4). Positive decrease
Multiple inlet irrigation for rice	96 (42%)	18 (19%)	10 (10%)	68 (71%)
Tailwater recovery and irrigation storage reservoir	114 (50%)	17 (15%)	33 (29%)	64 (56%)

Note: Shares are reported in parentheses. Columns 2–4 add up to be 100%.

Table 2. % decrease in pumping time for all producers and only producers reporting positive decrease

	Producers reported zero or positive decrease			Producers reported positive decrease			
Irrigation water management practice	(1). Mean	(2). Std. Dev.		(3). Mean	(4). Std. Dev.	(5). Min	(6). Max
Multiple inlet irrigation for rice	20.9	14.5		24	13	1	75
Tailwater recovery and irrigation storage reservoir	19.1	18.3		29	14.8	10	62.5

In the next step, we use descriptive analysis to see if pumping time reduction is correlated with any factors. For factors that are binary in nature, such as the dummy variable indicating a producer is a landowner, observations are put into two groups. The binary factor takes on the value of 1 (or "Yes") for one group and the value of 0 (or "No") for the other group. The average pumping time reduction is calculated and then compared for each group. For many of the binary factors, there was a noticeable difference in the average pumping time reduction between the two groups (Table 3). However, when *t* tests are used to test for the differences in the means of pumping time reduction between groups, the only difference in the means that is statistically significant is for the variable that indicates depth-to-groundwater increased in the last five years and only among producers that used tailwater recovery and on-farm storage reservoirs. Producers that noticed a depth-to-groundwater increase in the last five years reported significantly more pumping time reduction (27.5%) than producers that had not noticed a difference (17.8%). Among the users of multiple inlet irrigation, landowners reduced pumping time by an average of 20.3% while non-owners achieved an average of 23.1%. Among users of tailwater recovery/reservoir systems, landowners had a larger relative reduction in pumping time (19.7% versus 17.6%). For both irrigation methods, descriptive analysis showed that higher levels of education and flow meters installed on wells resulted in more significant pumping time reduction.

Table 3. Average pumping time reduction (%) and related binary factors

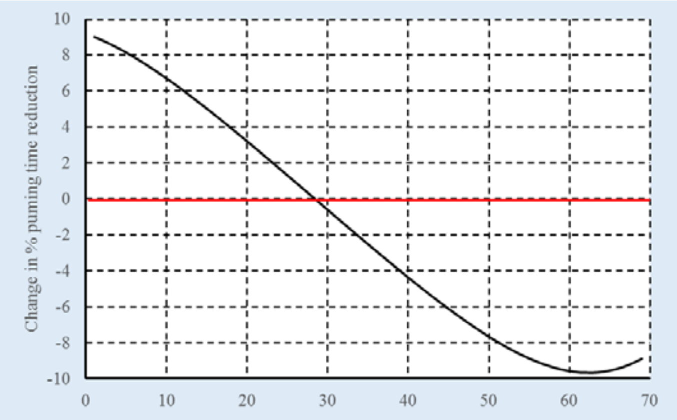
	Multiple Inlet Irrigation		Tailwater recovery and irrigation storage reservoir	
	Yes	No	Yes	No
Producer Characteristics:				
Landowner	20.3 (14.5)	23.1 (15.0)	19.7 (17.7)	17.6 (20.4)
Highest degree is Bachelor or above	21.7 (14.6)	19.5 (14.6)	19.6 (17.9)	18.5 (18.9)
Education agriculture-related	21.6 (13.7)	19.4 (16.3)	20.9 (19.0)	16.5 (17.2)
Farm Characteristics:				
Depth-to-groundwater increased in the last five years	16.2 (15.0)	21.5 (14.5)	27.5 (15.8)	17.8** (18.4)
Flow meters installed on wells	22.6 (13.9)	19.3 (15.2)	20.7 (19.0)	17.5 (17.5)
Region:				
White River zone	19.3 (14.2)	22.3 (14.8)	20.2 (16.5)	18.3 (19.4)
Delta zone	20.1 (13.9)	21.2 (14.8)	17.4 (21.2)	19.6 (17.3)
Grand Prairie zone	24.1 (14.0)	19.6 (15.6)	19 (18.4)	19.1 (18.3)

Note: Standard deviations are reported in parentheses; *, **, *** in the No column denote levels of statistical significance of the mean-comparison *t* tests are at 10%, 5%, and 1% respectively.

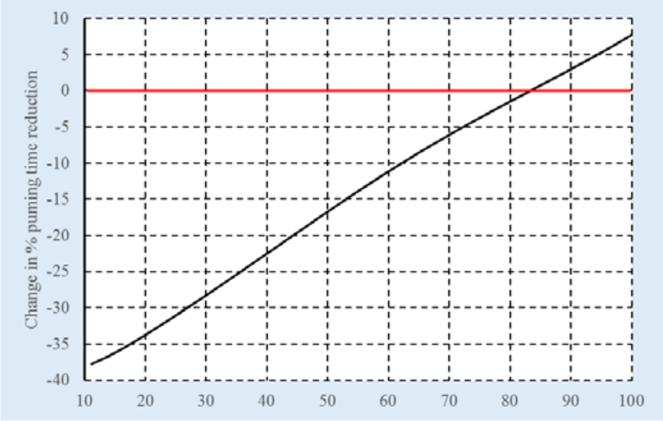
Producer characteristics have some predictive powers of the magnitude of pumping time reduction achieved by using MIRI (Table 4, Column 1). Ceteris paribus, having a bachelor's degree or above has a negative and statistically significant marginal effect on the size of pumping time reduction. This is somewhat unexpected. One possible explanation is that the implementation of multiple inlet irrigation requires a good amount of manual labor to lay pipes throughout fields and punch holes and install gates in the tubing. Producers with more education may be less willing to carry out such labor-intensive practices than others with less education. Having an agriculture-related education also has a negative marginal effect, but it is not statistically significant. This is counter-intuitive since agriculture-related education is expected to help producers improve farming skills. One possible explanation is that actual farming experience matters more than classroom education. Once farming experience is controlled for, education related to agriculture does not play a role. The finding that more or agriculture-related education does not seem to lead to a more effective implementation of IWM practices is not at odds with the findings from the literature on the adoption of soil and water conservation practices. More education increases the likelihood of adoption in some studies but has negative or no effects in others (Knowler and Bradshaw, 2007).

Since the squared term of years of farming experience is added (Table 4), its marginal effect is plotted (Figure 1). In the plots (Figure 1), standardized values are converted back to original values for a more straightforward interpretation. The Y-axis represents the change in pumping time reduction. The marginal effect of years of farming experience turns from positive to negative at around 29 years of farming experience (Figure 1, Panel a). This means that an additional year of farming increases the size of pumping time reduction, but the magnitude of reduction is shrinking. When years of farming surpass 29, an additional year of farming reduces the magnitude of pumping time reduction. The nonlinear relationship may be the result of several effects that years of farming could have on pumping time reduction. First, producers with more farming experience may be better at realizing the potential of MIRI to reduce pumping time. Second, since years of farming experience and age are highly correlated, the manual labor required to implement MIRI puts a strain on older (more experienced) producers. Third, younger (less experienced) producers may have an easier time using computer software, such as PHAUCET, that can enhance the performance of MIRI than older producers. As producers age, the second and third effects may dominate the first effect and turn the marginal effect from positive to negative. The marginal effect of household income is positive and statistically significant. The marginal effect for the percentage of household income from farming changes from negative to positive at about 84% of income (Figure 1, Panel b). For most sample producers that used MIRI (75%), more than 80% of their household income comes from farming. Thus, the positive marginal effect encompasses the majority of producers surveyed. Traditionally, lower income farmers are more likely to adopt new irrigation techniques to improve their incomes, whereas high income farmers are more likely to continue using traditional techniques passed down from previous generations. The finding that an increase in income led to more sizeable pumping time reductions was not expected and requires further investigation.

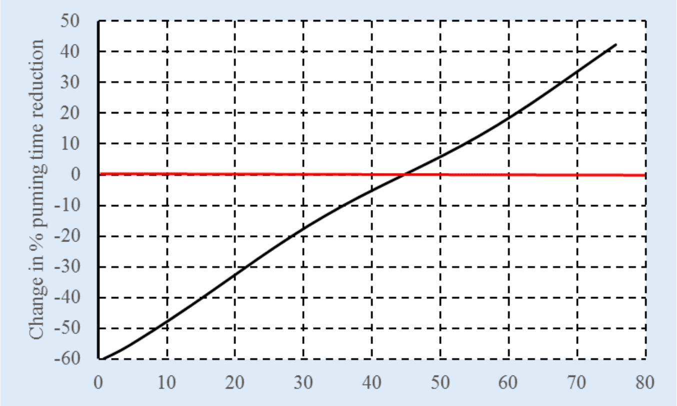
Some characteristics of farms influence pumping time reduction for MIRI (Table 4, Column 1). The marginal effect of the percentage of irrigated area allocated to rice is initially negative before the positive marginal effect kicks in at about 46% (Figure 3, Panel c). As more land is allocated to rice, more labor and expense is needed to implement MIRI. In the likely scenario that the labor supply is limited on-farm, a labor shortage may put a strain on the effective implementation of multiple inlet irrigation. However, in reality the labor demand is earlier, and after installation, the labor requirement is less for the rest of the season for checking paddy depths when MIRI is used. Meanwhile, since MIRI is often used on rice fields, producers that grow more rice may be more familiar with the practice. Producers located in the White River zone achieved lower levels of pumping time reduction than those in the Delta or Grand Prairie zones. One reason may be that since the water supply in the White River zone is scarcer, producers are already pumping less than those in other zones, so there is not much room for reducing pumping time further. The marginal effect of the Delta zone variable was negative but not statistically significant, indicating that producers located in the Delta zone are about the same as those in Grand Prairie zone in terms of reducing pumping time. Among the three variables that characterize water supply and wells on-farm, only the percentage of irrigation water from groundwater has a statistically significant marginal effect (Table 4, column 1). Its positive marginal effect makes sense. A higher percentage of irrigation water from groundwater means more groundwater is used on-farm, and thus, more of the water savings go towards reductions in pumping time (instead of the reduced amount of surface water diverted for irrigation). Neither of the other two variables (having flow meters installed on wells, an increase in depth-to-groundwater on-farm) seems to affect the size of pumping time reduction associated with multiple inlet irrigation.



Panel a. Years of farming experience



Panel b. % household income from farming



Panel c. % irrigated area in rice

Figure 1. Marginal effects of factors with squared terms in Table 4, multiple inlet irrigation
Note: Red line indicates a change in marginal effect from positive to negative or negative to positive

The marginal effects of relevant factors on pumping time reduction due to the use of a tailwater recovery and storage reservoirs are also reported (Table 4, Column 2). Producer characteristics have less of an impact on pumping time for tailwater recovery and storage reservoirs than for that of MIRI in realizing water saving potential (Table 4, Columns 1 and 2). Education, farming experience, and household income do not have statistically significant marginal effects. Only two producer characteristic variables are shown to be statistically significant. Unlike in the case of MIRI, among producers that used tailwater recovery and storage reservoirs, being a landowner-operator has a positive and statistically significant marginal effect on the magnitude of pumping time reduction. Irrigators that are also land owners may be more willing to improve land that they own and operate. Producers that operate but do not own the land may have a difficult time convincing absentee landowners that they should make capital improvements because they do not associate the improvement with an increase in profit, especially where land is taken out of production. The marginal effect of the percentage of income from farming changes from negative to positive at the point where farming contributes about 62% of household income (Figure 2, Panel a). The pattern of the marginal effects is consistent with that observed among producers that use MIRI and a similar explanation can be offered.

Some farm and water supply characteristics have predictive powers of the performance of tailwater recovery and storage reservoirs. Percentage of irrigated area with rice has a positive and statistically significant marginal effect (Table 4, column 2). An adequate supply of irrigation water is needed for rice and tailwater and irrigation storage reservoirs can provide additional water when groundwater is inadequate. Rice farmers would recognize the need for securing additional (or capturing existing) water resources before those that grow more drought tolerant crops such as soybeans. The marginal effect of the percentage of irrigation water from groundwater is first negative then becomes positive at about 40% (Figure 2, Panel b). The positive effect can be explained in the same way as MIRI. When more groundwater is depleted and flowrates decrease over time, more water savings may be realized in the form of pumping time reductions. One major difference in the results between the two IWM practices is for the depth-to-groundwater variable. Producers reporting a depth-to-groundwater increase in the last five years has a positive and statistically significant marginal effect on pumping time reduction for tailwater recovery and storage reservoirs. This makes sense because they likely installed tailwater recovery and storage reservoirs because they recognized a groundwater limitation from aquifer depletion. It is not really clear why MIRI farmers did not recognize a similar reduction when noticing an increase to groundwater depth. It may be because with MIRI they are able to irrigate their rice crop adequately, so they do not perceive the reduction in flow or capacity over time. Those that implemented irrigation storage and tailwater recovery systems may have experienced a water shortage and converted to surface water in response. The size of the irrigated area does not have a statistically significant marginal effect for either IWM practice. The potential increase in efficiency for larger farms may be offset by the increased potential for complications with equipment and farming operations.

A surprising result is that having flow meters does not generate statistically significant marginal effects on pumping time reduction for either IWM practice (Table 4, columns 1 and 2). The respondents were asked if they had any flow meters and how many were permanently mounted. Many reported having at least one meter (37%), but the analysis did not delineate between producers which had only a few meters or one on every pump. Perhaps if meters were more prevalent, relationships to other factors would have been significant. In future studies, asking producers more clearly about the amount of flow meters they have and where they are located may provide more significant results. Another variable that does not have a statistically significant marginal effect on pumping time for either IWM practice is the length of time that practice has been in use. The efforts by organizations such as the University of Arkansas, Division of Agriculture Cooperative Extension Service, and the USDA Natural Resource Conservation Service to help producers implement new IWM practices and then train them how to use these practices may help accelerate the learning curve. One other possible explanation is that producers get better at implementing the IWM practice with more experience, but the infrastructure tends to deteriorate over time, which essentially evens out the effects. Neither of the production zone variables had a statistically significant marginal effect for tailwater recovery and storage reservoirs (Table 4, column 2). However, producers located in the White River zone had a statistically significant and negative marginal effect on pumping time reduction for producers using multiple inlet irrigation (Table 4, column 1). This is perhaps because producers are using tailwater recovery and storage reservoirs to augment the water supply on-farm and thus may have already recognized that they need to rely less on groundwater.

Table 5. Tobit model, Marginal effects

Dependent variable: Pumping time reduction (%)	(1). Multiple inlet rice irrigation		(2). Tailwater recovery and storage reservoir	
Landowner	−1.702	(3.396)	8.249**	(4.030)
Highest degree is Bachelor or above	−11.11**	(4.191)	0.916	(3.751)
Education agriculture-related	−0.733	(4.476)	4.904	(4.163)
Years of farming experience			−0.0512	(0.130)
Years of farming experience, Standardized [a, b]	−1.719	(2.398)		
Years of farming experience, Standardized and Squared [a]	−3.239**	(1.584)		
Household 2014 pre-tax income ($1,000)	0.0550**	(0.0250)	−0.000965	(0.0271)
% household income from farming, Standardized [a, b, c]	−0.557	(3.725)	12.51***	(4.567)
% household income from farming, Standardized and Squared [a]	7.206**	(2.971)	8.928***	(2.681)
Total irrigated area (1,000 ha)	−1.223	(1.298)	−1.309	(2.081)
% irrigated area in rice			0.155*	(0.0868)
% irrigated area in rice, Standardized [a, b]	−23.01***	(7.279)		
% irrigated area in rice, Standardized and Squared [a]	17.50***	(5.805)		
% irrigation water from groundwater	0.177**	(0.0666)		
% irrigation water from groundwater, Standardized [a, c]			19.71*	(11.25)
% irrigation water from groundwater, Standardized and Squared [a]			9.375*	(5.524)
Depth-to-groundwater increased in the last five years	−8.000	(4.955)	12.15***	(3.994)
Flow meters installed on wells	−0.631	(3.613)	−1.160	(4.335)
Length of time the practice has been in use (months)	−0.00239	(0.00910)	−0.0101	(0.00801)
Size of largest reservoir on farm (10,000 m^3)			0.0357*	(0.0181)
Area of largest reservoir on farm, Standardized [a, c]			−12.15	(7.623)
Area of largest reservoir on farm, Standardized and Squared [a]			2.116	(1.436)
Depth of largest reservoir on farm, Standardized [a, c]			−22.17**	(11.08)
Depth of largest reservoir on farm, Standardized and Squared [a]			1.361	(0.847)
White River zone	−10.66**	(4.222)	−2.610	(5.056)
Delta zone	−2.122	(6.893)	−2.054	(6.187)
Inverse Mills Ratio for used the practice	−31.98***	(9.710)	−29.30***	(10.34)
Inverse Mills Ratio for knew pumping time reduction	−7.080	(7.325)	−16.32*	(9.289)
Observations	78		97	

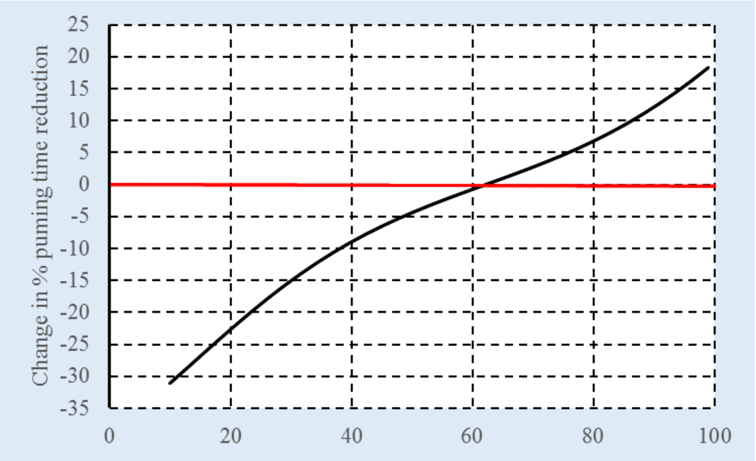
Robust standard errors are reported in in parentheses.

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

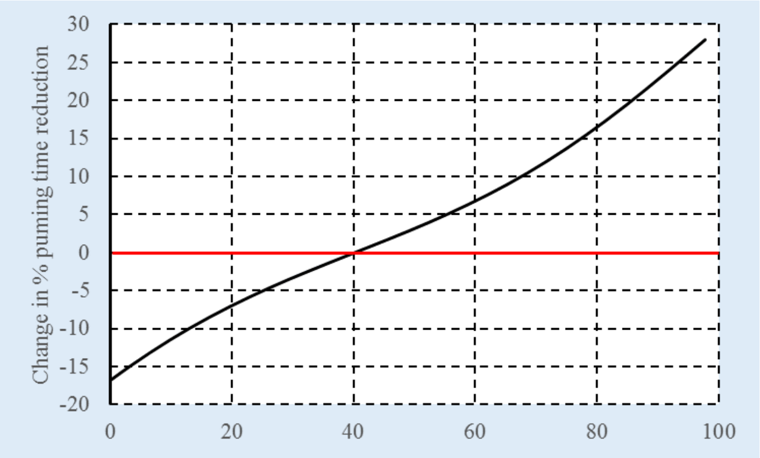
a. Estimated coefficients, not marginal effects, are reported.

b. Marginal effects are reported in Figure 3 for Tobit model on multiple inlet irrigation.

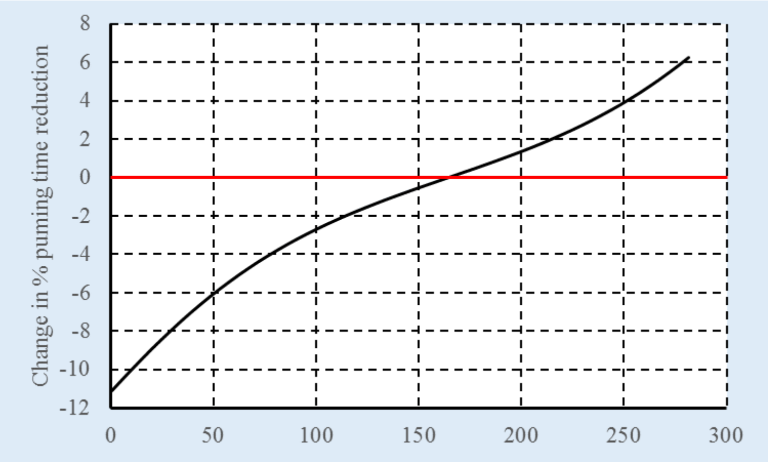
c. Marginal effects are reported in Figure 4 for Tobit model on tailwater recovery and storage reservoir



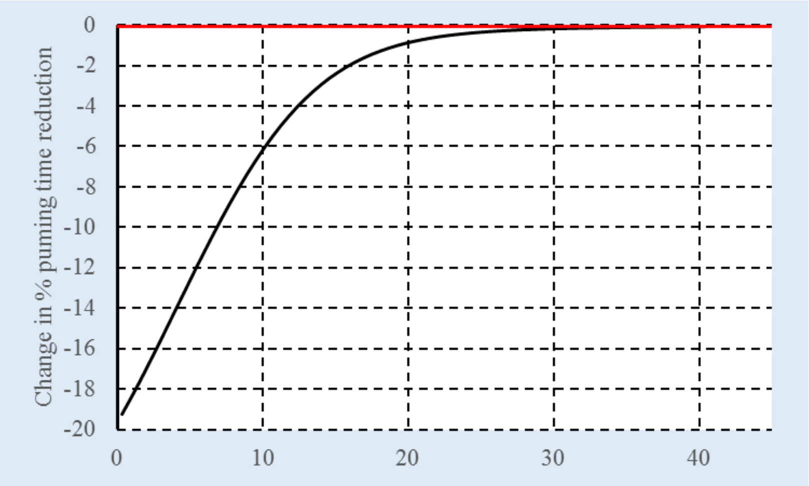
Panel a. % household income from farming



Panel b. % irrigation from groundwater



Panel c. Area of largest reservoir on farm (ha)



Panel d. Depth of largest reservoir (m)

Figure 2. Marginal effects of factors with squared terms in Table 4, tailwater recovery and irrigation storage reservoir

6. Conclusions

Using data from the 2016 Arkansas Irrigation Survey, this study first summarizes the on-farm effects of two Irrigation Water Management (IWM) practices, multiple inlet rice irrigation and tailwater recovery and irrigation storage reservoirs. The study then links the on-farm performance of the practices to a set of socioeconomic factors and characteristics of the farm and water supply. Descriptive statistics indicate large variations in pumping time reduction for producers using both IWM practices. A moderate amount of sample producers (29%) using tailwater recovery and irrigation storage reservoirs reported zero pumping time reduction, while others reported pumping time reductions as high as 75% (Table 1 and 2). Statistics for multiple inlet irrigation exhibit a similar trend. Large variations in performance indicate there is room for some producers to realize the full potential of both IWM practices. Follow up interviews with producers that reported the highest levels of pumping time reduction could provide helpful insight into strategies resulting in success for each IWM practice.

For multiple inlet irrigation, our results indicate that producer characteristics have a greater influence on pumping time than farm and water supply characteristics. An increase in formal education and years of farming experience both correlated with less significant reductions in pumping time. The manual labor associated with multiple inlet irrigation may be a reason for this relationship. An increase in income as well as a greater percentage of income from farming both had had positive effects on pumping time reduction. The only farm and water supply characteristics that were shown to influence the use of multiple inlet irrigation were percentage of irrigated area in rice and percentage of water irrigated from groundwater. Both of these variables resulted in greater pumping time reductions. Producers which irrigate a lot of their land with rice are likely more familiar with MIRI, while producers irrigating mainly with groundwater have more potential for pumping time reductions.

For tailwater recovery and irrigation storage reservoirs, farm and water supply characteristics have a greater impact on pumping time reduction than producer characteristics. Producers which reported an increase in depth-to-groundwater also reported more significant pumping time reductions. While it is unlikely that they actually measured their groundwater levels, they recognized improved water security and capacity for adding recovery and irrigation storage to their farms. This reduction in pumping time is consistent with the role of on-farm reservoirs as an infrastructure-based solution to convert irrigated hectares from groundwater to surface water. Similar to multiple inlet irrigation, percentage of land irrigated with rice and percentage of land irrigated with groundwater both had positive correlations with pumping time reduction. An increase in these two variables will typically lead to more runoff which tailwater recovery reservoirs are able to capture. Land ownership is a producer characteristic which influences pumping time. Operators that are also land owners may be more willing to improve land that they own and operate.

Our findings point to some policy changes that could be made to increase the effectiveness of the IWM practices studied. Large variations in pumping time suggest post-adoption assistance is needed to achieve the intended water savings of IWM practices. Understanding the factors that lead to success could help other producers maximize the effectiveness of IWM practices. Currently, most cost-share programs only offer financial assistance for the equipment purchase or initial installation. Programs that offer post-adoption assistance can be important as well. For example, if labor shortage were the reason behind the negative relationship observed between years of farming (for the range of 29 years or above) and the size of pumping time reduction, subsidizing the labor cost of implementing multiple inlet irrigation would help. These findings require further investigation. For example, follow-up questions in future surveys or focus groups with producers should be used to identify what successes and difficulties they have had in implementing IWM practices and why some factors help while other factors deter efforts to reduce pumping time.

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Appendix:

Table a1. Variable characteristics for each IWM practice

Variable	Multiple inlet rice irrigation		Tailwater recovery and storage reservoir		All Producers[1]	
	Mean	St Dev	Mean	St Dev	Min	Max
Landowner[2]	0.794	0.407	0.808	0.396	0	1
Highest Degree Bachelor or Above[2]	0.598	0.493	0.529	0.502	0	1
Education Agriculture-related[2]	0.649	0.480	0.577	0.496	0	1
Years of farming experience	31.8	16.0	33.7	15.7	1	73
Household 2014 pre-tax income ($1,000)	113.3	71.3	131.2	86.8	7.5	325
% of household income from farming	85.3	21.4	82.4	25.1	5	100
Total irrigated area (1,000 ha)	1.37	1.30	1.10	0.875	0.014	8.11
% irrigated in rice	38.3	16.2	35.8	21.9	0	100
% irrigation from groundwater	67.7	32.2	58.7	30.5	0	100
Depth-to-groundwater increases in the last five years[2]	0.112	0.319	0.144	0.338	0	1
Flow meter installed on wells[2]	0.454	0.500	0.500	0.502	0	1
Length of time practice has been in use (months)	188	176	264	247	1	797
Size of largest reservoir on farm (10,000 m^3)			0.759	2.27	0.001	18.6
Area of largest reservoir on farm (ha)			70.1	122.0	1	700
Depth of largest reservoir (m)			11.9	19.7	1	200
White River zone[2]	0.485	0.502	0.385	0.489	0	1
Delta zone[2]	0.216	0.414	0.240	0.429	0	1

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[1] All producers indicates the minimum and maximum variable values for producers using either multiple inlet rice irrigation or tailwater recovery and irrigation storage reservoirs

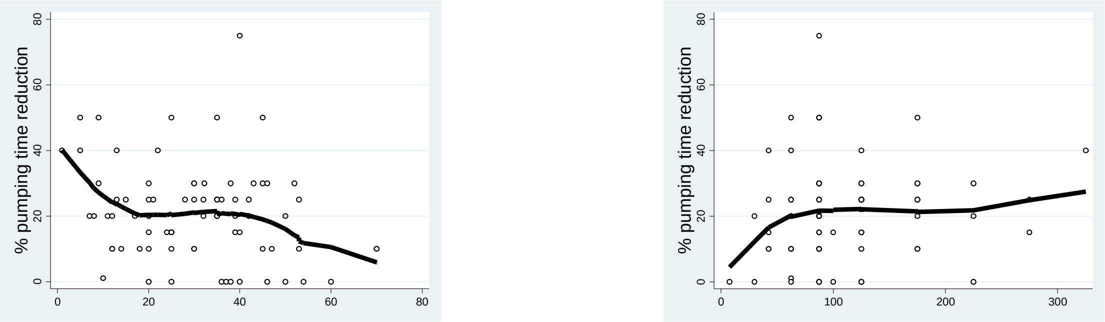
[2] Binary Variable where 1 indicates an answer of yes to the variable and 0 represents an answer of no

Table a2. Estimated coefficients of Tobit model, Initial specifications

Dependent variable: Pumping time reduction (%)	(1). Multiple inlet rice irrigation		(2). Tailwater recovery and storage reservoir	
Landowner	−2.340	(3.823)	10.40*	(5.977)
Highest degree is Bachelor or above	−12.45***	(4.585)	1.586	(5.692)
Education agriculture-related	−0.744	(4.756)	6.584	(6.136)
Years of farming experience	0.805*	(0.479)	0.240	(0.783)
Years of farming experience, Squared	−0.0143**	(0.00692)	−0.00648	(0.0105)
Household 2014 pre-tax income ($1,000)	0.0565**	(0.0279)	0.110	(0.125)
Household 2014 pre-tax income, Squared			−0.000279	(0.000372)
% household income from farming	−1.765***	(0.569)	−1.524***	(0.492)
% household income from farming, Squared	0.0110**	(0.00415)	0.0123***	(0.00375)
Total irrigated area (1,000 ha)	−1.604	(1.586)	−4.693	(3.090)
% irrigated area in rice	−2.504***	(0.746)	0.284**	(0.128)
% irrigated area in rice, Squared	0.0278***	(0.00903)		
% irrigation water from groundwater	−0.0342	(0.262)	−0.896*	(0.469)
% irrigation water from groundwater, Squared	0.00224	(0.00244)	0.0109**	(0.00533)
Depth-to-groundwater increased in the last five years	−8.228	(5.871)	13.56**	(5.937)
Flow meters installed on wells	0.298	(4.088)	−0.0799	(6.095)
Length of time the practice has been in use (months)	−0.00842	(0.0260)	0.0653	(0.0498)
Length of time the practice has been in use, Squared	0.0000120	(0.0000374)	−0.000104*	(0.0000584)
Size of largest reservoir on farm (10,000 m^3)			0.225***	(0.0588)
Size of largest reservoir on farm, Squared			−0.000133***	(0.0000437)
Area of largest reservoir on farm (ha)			−0.625***	(0.224)
Area of largest reservoir on farm, Squared			0.00149**	(0.000685)
Depth of largest reservoir on farm (m)			−5.507**	(2.096)
Depth of largest reservoir on farm, Squared			0.148***	(0.0367)
White River zone	−12.95**	(5.139)	−4.214	(6.768)
Delta zone	−2.863	(7.572)	0.0746	(7.878)
Inverse Mills Ratio for used the practice	−38.70***	(11.97)	−43.89***	(15.18)
Inverse Mills Ratio for knew pumping time reduction	−5.761	(8.687)	−25.17*	(14.21)
Constant	150.4***	(36.80)	58.13***	(17.97)
Observations	78		97	
AIC	606.9		658.9	

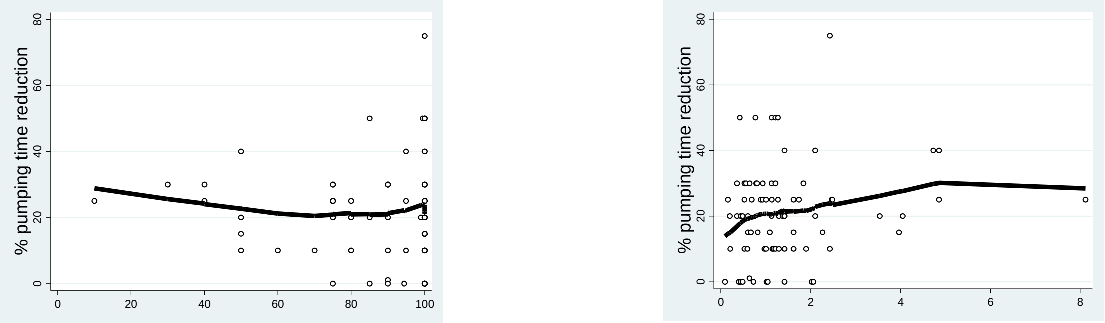
Robust standard errors are reported in in parentheses.

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



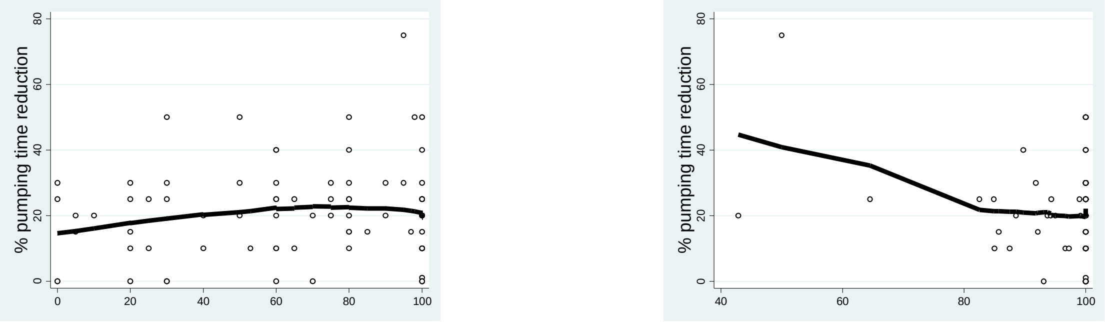
Panel a. Years of farming experience

Panel b. Household 2014 pre-tax income ($1,000)



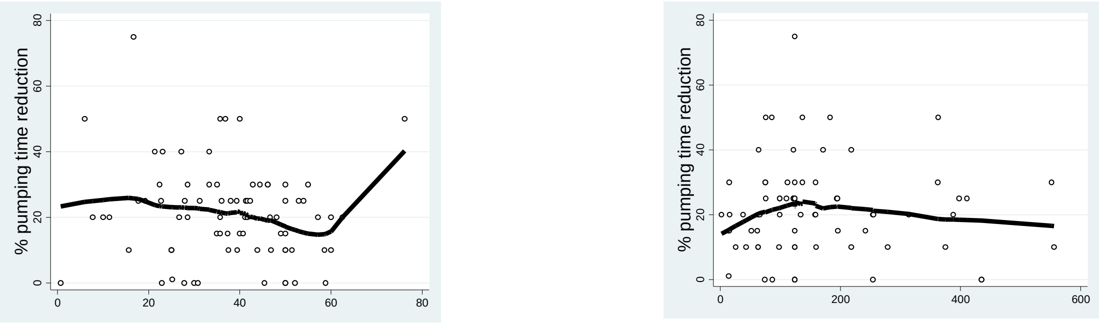
Panel c. % household income from farming

Panel d. Total irrigated area (1,000 ha)



Panel e. % irrigation water from groundwater

Panel f. % gravity irrigated area

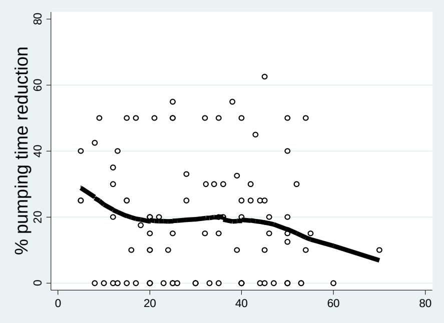


Panel g. % irrigated area in rice

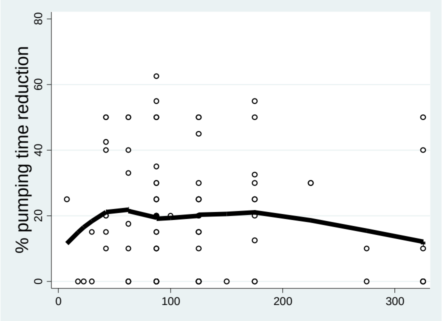
Panel h. Length of time in use (months)

Figure a1. Pumping time reduction due to the use of multiple inlet irrigation and related continuous factors

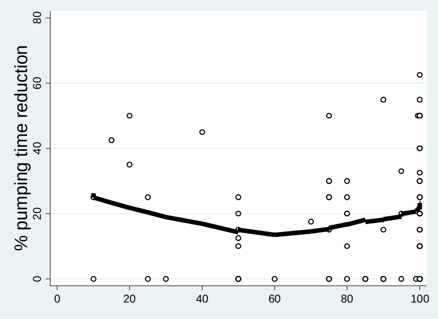
Note: Hollow circles are data points. Black bold lines are lines that connect smoothed values of pumping time reduction.



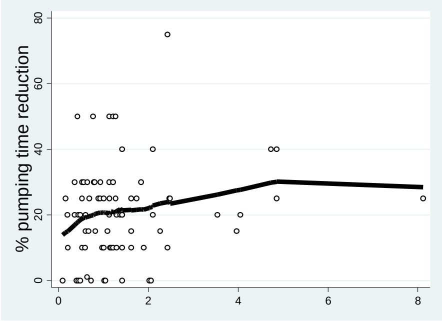
Panel a. Years of farming experience



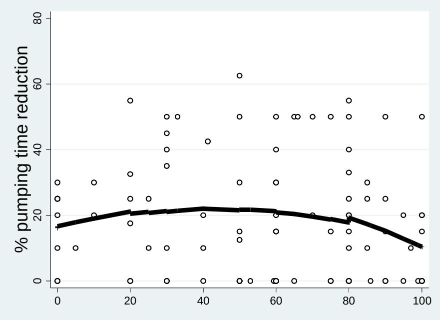
Panel b. Household 2014 pre-tax income ($1,000)



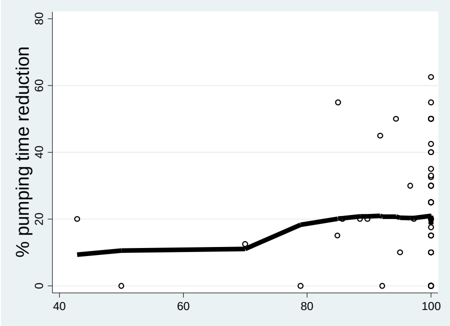
Panel c. % household income from farming



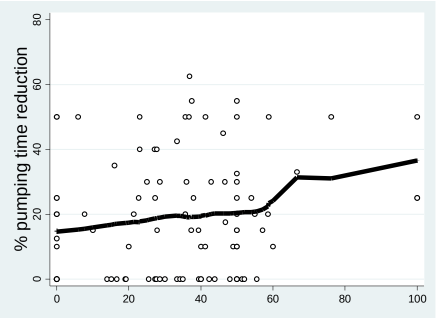
Panel d. Total irrigated area (1,000 ha)



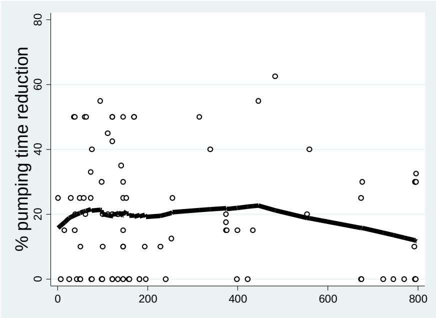
Panel e. % irrigation water from groundwater



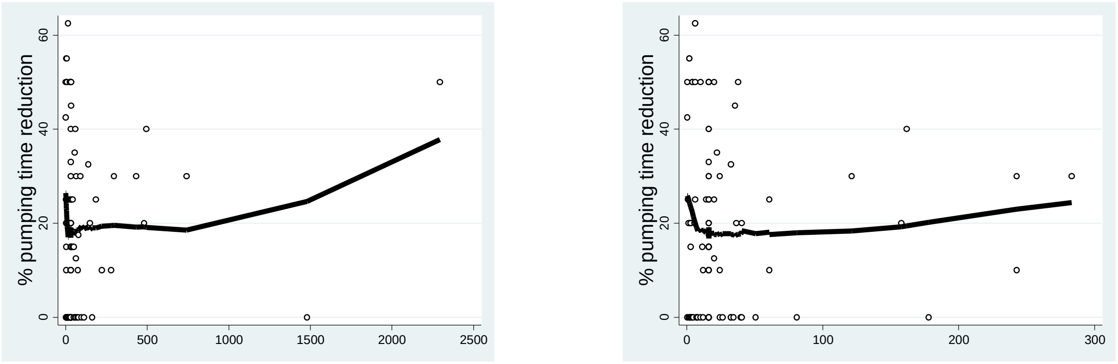
Panel f. % gravity irrigated area



Panel g. % irrigated area in rice

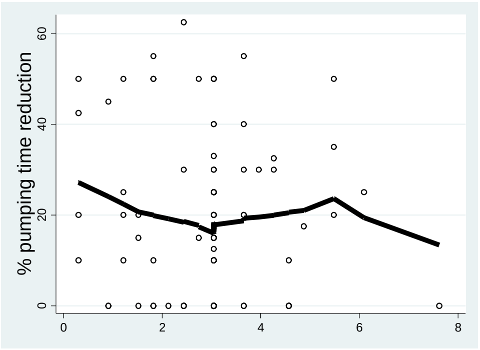


Panel h. Length of time in use (months)



Panel i. Size of largest reservoir on farm (10,000 m^3)

Panel j. Area of largest reservoir on farm (ha)



Panel k. Depth of largest reservoir on farm (m)

Figure a2. Pumping time reduction due to the use of tailwater recovery and reservoir and related continuous factors