Farmers' demand for water management information

by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Abstract

This research extends the Feder and Slade (1984) model of information acquisition by assuming information has both monetary and time costs. Farmers may substitute between different types of information given differences in these two costs. This generalized model is used to develop hypotheses about factors affecting farmers' demand for water management information. These hypotheses are then tested using a special tabulation of the USDA Farm and Ranch Irrigation Survey provided by USDA's Economic Research Service. The cross tab data on sources of information used to conserve water and reduce irrigation costs and methods to schedule irrigation are stratified by farm size, year and state for 17 Western States.

Main results are as follows. The total number of information sources to manage water and irrigation scheduling methods increases with farm size and decreases with the proportion of farmers over 65. While measures of drought did not have a significant effect on information demand, a history of wetter than normal years discouraged information demand. Water costs do not affect the number of information sources or scheduling methods used, but do affect choice among different methods. Higher water costs encouraged greater use of more management intensive methods. The total number of information sources used was decreasing in the proportion of farmers who were Hispanic. This comes from less use of private, but not public, information sources.

1. Introduction

Improved efficiency in irrigation is one possible, important way to balance water supply and demand. In the United States, 80%-90% of consumptive water is used in irrigated agriculture (Schaible and Aillery, 2012). A substantial portion of total water applied in irrigation could just be water loss or be used ineffectively, due to field water runoff, excess evaporation, transpiration by noncropped biomass, and percolation below the crop-root zone (Schaible and Aillery, 2012). Water loss in irrigation not only diverts water from beneficial uses, but also contributes to water pollution.

As the 'hardware' of irrigation, physical irrigation systems have long been tools to improve the efficiency of irrigated water. More efficient gravity systems (such as above or below ground pipe, lined open ditch field water delivery systems) and more efficient pressure-sprinkler systems (such as drip or trickle systems, lower pressure sprinkler systems) have been adopted on an increasing portion of total irrigated acres in 17 western states of the US (Schaible and Aillery, 2012). These more efficient systems, especially more efficient pressure systems, are supposed to decrease water runoff, evaporation and other water loss, and therefore improve irrigated water efficiency.

In addition to physical systems, water management information and decision tools (the 'software' of irrigation) have potential to improve the efficiency of irrigation applications. There are four modern management-intensive irrigation-scheduling methods farmers may use. These include soil-moisture sensing devices, plant-moisture sensing devices, commercial-scheduling services, and computer simulation models. Among these four, however, the highest adoption rate is no more than 25% of total irrigated farms in 17 western states of the United States. The adoption rates are calculated based on data from the Farm and Ranch Irrigation Survey (FRIS) of the U.S. Department of Agriculture (USDA). Even if we combine the four methods together to consider farms that adopt at least one (meaning farms choose one or more of the four methods), modern, management-intensive scheduling method, the adoption rate is no more than 35%. These low adoption rates of modern, management-intensive scheduling methods indicate that there is great potential to improve the efficiency of irrigation scheduling.

The knowledge of farmers' demand for water management methods or information should help make more effective policies aimed to encourage the adoption of management-intensive water management practices.

2. Literature review

The adoption of modern, physical irrigation technology, such as improved gravity systems and pressure systems, has been extensively modeled and reported in the literature (Caswell and Zilberman, 1986; Negri and Brooks, 1990; Dinar et al., 1992; Green et al., 1996; Olen et al., 2012). However, relatively few studies have focused on the adoption of efficient water management in irrigation (Parker and Zilberman, 1996; Leib et al., 2002; Skaggs and Samani, 2005; Bjornlund et al., 2009).

Schaible and Aillery (2012) reported in detail that more efficient gravity irrigation systems (relative to less efficient gravity irrigation) and more efficient pressure-sprinkler irrigation systems (relative to less efficient gravity irrigation) have been increasingly used. They also noted that such improvement in physical irrigation systems is not sufficient to relieve the pressure on irrigation agriculture posed by increasing water demand and limited supply. While the authors noted the importance of water management, they provide only a brief description of the role of irrigation scheduling methods.

Frisvold and Deva (2012) used published cross-tab data from the 1998 Farm and Ranch Irrigation Survey provided by the USDA Economic Research Service to determine the effects of farm size on irrigation water management practices. These included the choices of information sources for water management, the adoption of modern scheduling methods, and participation in cost share programs that encourage adoption of improved irrigation technologies. Data were stratified by state and farm size, so that each observation corresponded to a state-farm size pair for 17 Western States and four farm size classes. Parametric and nonparametric measures of association showed that: 1) Low-cost, general information was used more frequently by all farms regardless of size, while larger farms were more likely to use information from private sources; 2) larger farms were also more likely to use information provided directly, while smaller farms got more of their information from intermediaries; 3) larger farms were more likely to use modern scientific methods for irrigation scheduling and to participate in government programs encouraging adoption of improved irrigation practices.

This research follows Frisvold and Deva (2012), focusing on water management practices, specifically choice of irrigation information source and adoption of irrigation scheduling methods. Moreover, this research will establish a formal modeling framework and comprehensively consider multiple factors that are potentially influential beyond farm size. Frisvold and Deva (2012) conducted contingency table analysis, examining associations between irrigation practices and farm size only. The approach applied here follows a multivariate regression approach that considers the effects of factors in addition to farm size.

The approach taken here follows the theoretical framework developed by Feder and Slade (1984) to understand farmer use of information. Their interest was the role of information use in the adoption of Green Revolution technologies. They considered the relationship between information and one specific input (fertilizer). Feder and Slade (1984) extended the work of Kislev and Shchori-Bachrach (1973) – which only considered the general effect of information, and the information acquired costlessly through passive learning – in two ways. First, Feder and Slade (1984) considered how information increased the efficiency of a specific input (rather than increasing productivity more generally). Second, they added active information acquisition that involved a monetary cost. The amount of information to acquire was modeled as a choice variable in production.

From this extended theoretical model, Feder and Slade (1984) reasoned that at the earlier stages of information diffusion, farmers that are either larger, have access to information, or have more human capital, actively obtain more information. Therefore, these farmers would also increase use of the input whose efficiency is enhanced by information acquisition. Because of scale economies in applying information across acres, larger farmers would have higher initial adoption rates of both information and the modern input. In the long run, use of information and the modern input would follow a diffusion curve so that adoption rates would converge to an adoption ceiling among farmers regardless of their sizes, access to information, or human capital.

Another model relevant to this thesis is that of Caswell and Zilberman (1986) who considered the choice between adopting traditional gravity irrigation versus more modern sprinkler irrigation methods. In their model, the effective amount of water depended on the choice of technology and exogenous land quality. Land quality increased the efficiency of water applications in much the same way that information increased the efficiency of the modern input in Feder and Slade's (1984) model.

A difference is that land quality is exogenous and not a choice variable. While in Feder and Slade (1984) information affected demand for the modern input, in Caswell and Zilberman (1986), land quality affected demand for irrigation water. In Caswell and Zilberman (1986), the choice of irrigation technology is a two-part decision. First, given each technology (gravity or sprinkler), farmers choose the amount of water that maximizes profit. Then, farmers compare maximum profits under different technology to decide which technology to adopt. Farmers choose the "modern" irrigation technology if it is more profitable. Relative profitability of technologies depends on land quality, well depth, water costs, and initial system efficiency.

Because of the complex interactions of many variables, the effects of exogenous variables on water demand were ambiguous. To obtain more definitive results, Caswell and Zilberman (1986) compared outcomes under Cobb-Douglas and quadratic production function specifications. They found that when the quality of farmland is low or the water price is high, farmers were more likely to use more efficient irrigation technology. They also showed that a production specification allowing for changing elasticity of water's productivity (the quadratic model) yielded results that are more reasonable. Predicted water use and the elasticity of marginal effect of effective water from the quadratic model were relatively consistent with real data.

The theoretical framework in this thesis builds on elements of the frameworks of Feder and Slade (1984) and of Caswell and Zilberman (1986). As in Feder and Slade (1984), it allows for both passive and active information acquisition, where actively acquired information entails costs. As in Caswell and Zilberman (1986), it considers water as the primary input of interest. Demand for water depends on parameters characterizing the underlying efficiency of water applications. While in Caswell and Zilberman (1986), efficiency is exogenously determined (by factors such as land quality). The approach used here is more like Feder and Slade (1984) in that input (in this case water) efficiency depends on information, which is also a choice variable.

The approach here extends the Feder and Slade approach in that actively acquired information entails two types of cost. One is a monetary cost, as in Feder and Slade (1984). Another is the time cost of obtaining and processing irrigation information for decision-making. Costs of information are assumed to vary by type of information. Some more, scientifically based information may be more intensive in management time. The monetary cost of information acquisition can also vary. For example, farmers may obtain information from extension or USDA specialists at no charge or they may pay for the services of private consultants. In other cases, farmers face a trade-off between time costs and monetary costs. Hiring irrigation scheduling services may cost money, but save a farmer's management time. Both the Feder and Slade and Caswell and Zilberman approaches focus on a single input, treating acreage as a fixed, exogenous variable. The framework introduced below extends analysis to allow for two inputs: land and water, where both water and land use are choice variables.

The analysis will also consider how drought indicators affect demand for irrigation management information. Ding, Schoengold, and Tadesse (2009) presented a framework in which farmers' choose different tillage methods based on the comparison of optimal profits across different tillage practices. Their framework assumes that weather has smaller marginal effects under conservation tillage than conventional tillage. Using the Palmer Drought Severity Index (PDSI) and system equations, the authors examined the adoption of different tillage practices, and found that when drought occurs frequently in the previous five years, farms are more likely to use conservation tillage. This method of tillage is intended to help keep soil moist, and therefore is more efficient tillage practice. Thus, our analysis will examine the question of whether drought conditions increase demand for irrigation management information.

Time spent off-farm is also a factor that could influence technology adoption. Fernandez-Cornejo (2007) combined the decision of farming input and output, the adoption of agriculture technologies, and the decision of off-farm activities into one model framework by maximizing farmers' utility subject to an income constraint, a technology constraint, and a time constraint. The time constraint implies that there is a tradeoff between the time spent on technology adoption and the time spent on off-farm activities. Empirically, the authors examined off-farm income instead of the amount of time that is spent off-farm, since time spent off-farm is unobservable. Using data on the four technologies including both managerial intensive technologies and managerial-saving technologies, they estimated a two-stage model (instrumental variable). The estimation results showed that when farmers adopt managerial intensive technology, which requires more time, they tend to have lower off-farm income.

Water cost is another factor that potentially influences irrigated water demand and in turn irrigation information demand. Moore, Gollehon, and Carey (1994) examined the effects of water cost on water demand in a multi-crop production model. They found that at the crop level, water price does not significantly influence the short run water demand. However, water price does influence crop choices and cropland allocation, because crops vary in water requirement. Water price also influences the adoption of irrigation technologies, because different irrigation technologies require different amounts of water. These influences of water price on land allocation depend on long run adjustments, and could be positive or negative. At the farm level, water price negatively influences water demand, but the influence is inelastic.

Demographic characteristics of farmers are also factors that researchers have taken into consideration when analyzing irrigation practices. Negri, Gollehon and Aillery (2005) modeled the choice of irrigation as a discrete decision and treated the irrigation choice as a response to adverse climate. Using farm-level data, they examined the effects of climate, energy cost, water availability, demographic characteristics of farmers, etc. on the irrigation decision. The authors used water availability instead of water price, because the price of surface water was not considered a rational reflection of market demand and supply, and the availability of ground water indicates the shadow price of water. Estimation results from their probit model showed that precipitation negatively influences adoption of irrigation (compared to dryland production), while water availability had a significant positive influence. The estimate of water availability (the shadow price of water) could be biased, since water price is endogenous to climate. They also found that energy price in irrigation (pumping ground water) was not statistically significant. This might be because the energy price they used was a state-level average data and thus the state-level variation is not adequate to explain farm-level irrigation decisions. In addition, demographic characteristics turned out to have significant effects on irrigation adoption. Age had significant negative effects on irrigation adoption, while education had significant positive effects.

3. Theoretical Model

3.1 Demand for individual information

As part of on-farm water management, irrigation information should influence the efficiency of the irrigated water. We start with a one-input production function, where water is the only input and a multiplicative term represents the efficiency of water. This multiplicative term is a function of irrigation information, since irrigation information could contribute to water efficiency. The specification of the production function is as follows:

$$(1) \qquad Y = A \cdot f(\boldsymbol{h}(k) \cdot w)$$

Where Y is output, A is farm land size or acres, $f(\cdot)$ is the per acre production function, k is irrigation information, $\boldsymbol{h}(\cdot)$ represents the water efficiency attributed to irrigation information, w is applied water, and $\boldsymbol{h}(k) \cdot w$ is the effective water or beneficially used water denoted by *e(k, w)*. Both $f(\cdot)$ and $\boldsymbol{h}(\cdot)$ are well-behaved production functions, which means effective water and information have positive marginal productivities but the marginal productivities are decreasing, i.e.,

$$(2) \qquad f' > 0, f'' < 0; \ \boldsymbol{h}' > 0, \boldsymbol{h}'' < 0$$

In terms of information cost, we consider both the money farmers pay to obtain information and the time farmers spend to process and finally use information. Money cost is simply price time quantity, while time cost enters the profit function as a time constraint, as shown below. The farmers' profit maximum objective function is:

$$(3) \qquad Max_{k,w}\, \pi_0 = P \cdot A \cdot f(h(k) \cdot w) - r_w \cdot w - r_k \cdot k + r_T(T - tA - \tau_0 k)$$

Where π_0 is profit, information k and applied water w are choice variables, P is output price, r_w is water price, r_k is information price, $T = tA + \tau_0 k$ is the time constraint, T is the available time for farming, t is the time required for per acre farming, τ_0 is the time required for adopting per unit of information, and r_T is the shadow price of the available time T and reflects the change in profit caused by unit change in available time amount. The time constraint allows us to consider effects of farmers' available time T on the adoption of information k . We can see that farmland size (acres) is also included in the time constraint, because farming on larger land requires more time.

First order necessary conditions for this profit maximum problem are:

$$(4) \qquad \frac{\partial \pi_0}{\partial \mathbf{w}} = P \cdot A \cdot f' \cdot h - r_w = 0$$

$$(5) \qquad \frac{\partial \pi_0}{\partial k} = P \cdot A \cdot f' \cdot w \cdot \mathbf{h}' - r_k - r_T \cdot \tau_0 = 0$$

From the total differentials of (4) and (5), we obtain the comparative static analysis results shown in Table 1.

Table 1 Comparative static analysis: one-input production function $f(h(k) \cdot w)$

	dK	dW
dP	$+$	$+$
dA	$+$	$+$
dr_w	$-$, if $f'' \cdot h \cdot w + f' > 0$ $+$, if $f'' \cdot h \cdot w + f' < 0$	$-$
dr_K	$-$	$-$, if $f'' \cdot h \cdot w + f' > 0$ $+$, if $f'' \cdot h \cdot w + f' < 0$
dr_T	$-$	$-$, if $f'' \cdot h \cdot w + f' > 0$ $+$, if $f'' \cdot h \cdot w + f' < 0$
$d\tau_0$	$-$	$-$, if $f'' \cdot h \cdot w + f' > 0$ $+$, if $f'' \cdot h \cdot w + f' < 0$

From Table 1, we can see that the adoption of information increases with output price and land size, but decreases with information price. The shadow price of time has a negative effect on information adoption, which indicates that the available time positively influences the adoption of information. The effect of water price on information adoption depends on the sign of $f'' \cdot h \cdot w + f'$, which could be interpreted from the perspective of the elasticity of the marginal productivity of effective water. The elasticity of the marginal productivity of effective water is expressed as:

$$(6) \quad elasticity = -\frac{dMPP_e/MPP_e}{de/e} = -\frac{dMPP_e}{de} \cdot \frac{e}{MPP_e} = -\frac{df'}{de} \cdot \frac{e}{f'} = -f'' \cdot \frac{h(k) \cdot w}{f'}$$

Where e is effective water as explained above, and it is a function of information and applied water and is expressed as $e(k, w) = h(k) \cdot w$.

Given the assumption that $f' > 0$, when the elasticity of the marginal productivity of effective water is larger than 1, water price has a positive effect on information adoption; otherwise, a negative effect exists.

Another way to interpret $f'' \cdot h \cdot w + f'$ is that its sign reflects the complementary or competitive relationship between information and applied water. Whether information and applied water are complementary or competitive inputs depends on the effect of information (water) on the marginal productivity of applied water (information). This effect could be expressed as:

$$(7) \qquad \frac{\partial f / \partial w}{\partial k} = \frac{f' \cdot \boldsymbol{h}(k)}{\partial k} = f'' \cdot w \cdot \boldsymbol{h}' \cdot \boldsymbol{h} + f' \cdot \boldsymbol{h}' = \boldsymbol{h}'(f'' \cdot w \cdot \boldsymbol{h} + f')$$

Given the assumption that $\boldsymbol{h}' > \mathbf{0}$, the relationship between information and applied water alone determines the sign of $f'' \cdot h \cdot w + f'$, and in turn the direction of the effect of water price on information adoption. When the relationship between information and applied water is competitive, water price has a positive effect on information adoption; otherwise, water price has a negative effect on information adoption.

Specifically, assigning logarithmic functions to both $f(\cdot)$ and $\boldsymbol{h}(\cdot)$, we get Cobb-Douglas specification and comparative static analysis as shown in Table 2.

Table 2 Comparative static analysis: specific one-input production function

$$f(\boldsymbol{h}(k) \cdot w) = (k^{\alpha} w)^{\beta},\ 0 < \alpha < 1, 0 < \beta < 1$$

$$(1 - \beta - \alpha\beta) > \mathbf{0} \quad \textit{to make sure the return to scale is decreasing}$$

	dK	dW
dP	+	+
dA	+	+
dr_W	−	−
dr_K	−	−
dr_T	−	−
$d\tau_0$	−	−

From Table 2, we can see that the Cobb-Douglas specification only allows for the negative effect of water price on information adoption. If we choose the Cobb-Douglas production function to stress the problem of irrigation information adoption, we implicitly rule out the possibility that water price could have a positive effect on information adoption.

Extending the above model to include two inputs besides information, we have the following objective function:

$$(8) \qquad Max_{k,w,A}\ \pi_0 = Pf(A, h(k)w) - r_A \cdot A - r_w \cdot w - r_k \cdot k + r_T(T - tA - \tau_0 k)$$

Where farmland (acres) A is a choice variable instead of a given parameter (as it is in preceding one-input model), and r_A is land price. Again $f(\cdot)$ and $h(\cdot)$ are well-behaved production functions, which means effective water, land size and information have positive marginal productivities but the marginal productivities are decreasing, as shown below.

$$(9) \qquad f_1 > 0, f_2 > 0, f_{11} < 0, f_{22} < 0;\ h' > 0, h'' < 0$$

Following the same procedure we implemented while analyzing the one-input model, we do comparative static analysis of this two-input model, the results of which are shown in Table 3.

Table 3 Comparative static analysis: two-input production function $f(A, h(k)w)$

	dK	dW	dA
dP	$+$, if $f_{12} > 0$?, if $f_{12} < 0$	$+$, if $f_{12} > 0$?, if $f_{12} < 0$	$+$, if $f_{12} > 0$?, if $f_{12} < 0$
dr_A	$-$, if $f_{12} > 0$ $+$, if $f_{12} < 0$	$-$, if $f_{12} > 0$ $+$, if $f_{12} < 0$	$-$
dr_w	$-$, if $hw(f_{11}f_{22} - f_{12}^2) + f_{11}f_2 < 0$?, if $hw(f_{11}f_{22} - f_{12}^2) + f_{11}f_2 > 0$	$-$	$-$, if $f_{12} > 0$ $+$, if $f_{12} < 0$
dr_K	$-$	$-$, $hw(f_{11}f_{22} - f_{12}^2) + f_{11}f_2 < 0$?, if $hw(f_{11}f_{22} - f_{12}^2) + f_{11}f_2 > 0$	$-$, if $f_{12} > 0$ $+$, if $f_{12} < 0$
dr_T	$-$, if $f_{12} > 0$?, if $f_{12} < 0$	$-$, if $f_{12} > 0$, and $hw(f_{11}f_{22} - f_{12}^2) + f_{11}f_2$?, otherwise	$-$, if $f_{12} > 0$?, if $f_{12} < 0$
$d\tau_0$	$-$	$-, if\ hw(f_{11}f_{22} - f_{12}^2) + f_{11}f_2 < 0$ $+, if\ hw(f_{11}f_{22} - f_{12}^2) + f_{11}f_2 > 0$	$> 0, if\ f_{12} < 0$ $< 0, if\ f_{12} > 0$

From Table 3, we see that the effects of output price, land price and the available time (the shadow time price) on information adoption depends on the sign of f_{12}, which is the effect of land size (effective water) on the marginal productivity of effective water (land size) and reflects the relationship between land size and effective water. When $f_{12} > 0$, namely land size and effective water are complementary, output price positively influences information adoption, while land price negatively influences information adoption. When $f_{12} < 0$, namely the two inputs are competitive, the direction of the effect of output price is indefinite, while the effect of land price on information adoption is positive. The effect of the available time on information adoption is reflected through the effect of the shadow time price on information adoption. When $f_{12} > 0$, namely land size and effective water are complementary, the shadow time price has a negative effect on information adoption, which indicates that the available time has a positive effect. Otherwise, the direction of the effect of the available time is indefinite.

Meantime, the effect of water price on information adoption depends on the sign of $hw(f_{11}f_{22} - f_{12}^2) + f_{11}f_2$, which could be interpreted from the perspective of the elasticity of the marginal productivity of effective water. The expression of the elasticity of the marginal productivity of effective water is as below:

$$(10) \quad elasticity = -\frac{dMPP_e/MPP_e}{de/e} = -\frac{dMPP_e}{de} \cdot \frac{e}{MPP_e} = -\frac{df_2}{de} \cdot \frac{e}{f_2} = -f_{22} \cdot \frac{h(k) \cdot w}{f_2}$$

Given the assumption that $f_2 > 0$ and $f_{11} < 0$, when the elasticity of the marginal productivity of effective water is larger than 1, the direction of the effect of water price on information adoption is indefinite; otherwise, water price has a negative effect on information adoption.

As we did in the one-input model, the sign of $hw(f_{11}f_{22} - f_{12}^2) + f_{11}f_2$ could also be interpreted from the perspective of the complementary or competitive relationship between information and applied water. Whether information and applied water are complementary or competitive depends on the effect of information (applied water) on the marginal productivity of applied water (information), as shown in formula (11).

$$(11) \quad \frac{\partial f/\partial w}{\partial k} = \frac{\partial f_2 \cdot h(k)}{\partial k} = f_{22} \cdot w \cdot h' \cdot h + f_2 \cdot h' = h'(f_{22} \cdot w \cdot h + f_2)$$

Given the assumption that $h' > 0$ and $f_{11} < 0$, when information and applied water are competitive, the direction of the effect of water price on information adoption is indefinite; when information and applied water are complementary, water price has a negative effect on information adoption.

Specifically, assigning the specification of constant elasticity of substitute (CES) to above two-input production function, we get results of information demand as shown in Table 4.

Table 4 Comparative static analysis: specific two-input production function

$$f(A, \boldsymbol{h}(k)w) = (\alpha A^{-\rho} + (1-\alpha)(k^{\varepsilon}w)^{-\rho})^{-\frac{\gamma}{\rho}}, 0 \leq \alpha \leq 1, \rho \geq -1, \gamma > 0, \varepsilon > \mathbf{0}$$

$$1 - \gamma(\varepsilon + \mathbf{1}) > 0 \ to\ make\ sure\ t\mathbf{he}\ return\ to\ scale\ is\ decreasing$$

	dK	dW	dA
dP	$+$, if $\gamma + \rho > \mathbf{0}$?, if $\gamma + \rho < \mathbf{0}$	$+$, if $\gamma + \rho > \mathbf{0}$?, if $\gamma + \rho < \mathbf{0}$	$+$, if $\gamma + \rho > \mathbf{0}$?, if $\gamma + \rho < \mathbf{0}$
dr_A	$-$, if $\gamma + \rho > \mathbf{0}$ $+$, if $\gamma + \rho < \mathbf{0}$	$-$, if $\gamma + \rho > \mathbf{0}$ $+$, if $\gamma + \rho < \mathbf{0}$	$-$
dr_w	$-$, if $\rho < \mathbf{0}$?, otherwise	$-$	$-$, if $\gamma + \rho > \mathbf{0}$ $+$, if $\gamma + \rho < \mathbf{0}$
dr_K	$-$	$-$, if $\rho < \mathbf{0}$?, otherwise	$-$, if $\gamma + \rho > \mathbf{0}$ $+$, if $\gamma + \rho < \mathbf{0}$
dr_T	$-$, if $\gamma + \rho > \mathbf{0}$?, if $\gamma + \rho < \mathbf{0}$	$-$, if $\rho < \mathbf{0}$?, otherwise	$-$, if $\gamma + \rho > \mathbf{0}$?, if $\gamma + \rho < \mathbf{0}$
$d\tau_{\mathbf{0}}$	$-$	$-, if\ \gamma + \rho > \mathbf{0}$ $+, if\ \gamma + \rho < 0$	$-, if\ \gamma + \rho > \mathbf{0}$ $+, if\ \gamma + \rho < 0$

Different from the Cobb-Douglas production function we took as an example for one-input production analysis, the CES specification here allows for both positive and negative effects of output price, land price, water price, and the available time on information demand.

3.2 Structure of multiple information demand: time vs. money

Given that both money cost and time cost are involved in adopting information, the substitution between money and time offers farmers a way to flexibly adapt their information adoption to time constraints. They could adjust the structure of information, by shifting from low-cost but time-consuming information to costly but time-conserving information or vice versa. They could also choose different ways to adopt particular information: to spend money hiring information processors and assistants, or to spend time processing information.

In order to analyze farmers' choices between spending time and spending money, we consider two profit functions (12) and (13):

$$(12) \quad \pi_0 = P \cdot A \cdot f(h(k) \cdot w) - r_w \cdot w - r_k \cdot k + r_T(T - tA - \tau_0 k)$$

$$(13) \quad \pi_1 = P \cdot A \cdot f(h(k) \cdot w) - r_w \cdot w - r_k \cdot k - Z + r_T(T - tA - \tau_1 k)$$

Where π_0 is the profit function when farmers spend money cost r_k and τ_0 amount of time for unit information; π_1 is the profit function when farmers spend extra money Z so that the time spent in adopting information decreases to τ_1, $\tau_1 < \tau_0$.

Whether farmers substitute time for money or substitute money for time depends on which one of the two is more profitable. If $\pi_1^* - \pi_0^* > 0$, farmers substitute time for money, otherwise they spend more time on information adoption.

Using the Cobb- Douglas specification in the preceding part as a simple example, we examine exogenous conditions for the substitution between money cost and time cost. First, we solve two profit maximization problems (Max π_0 and Max π_1) to get two optimal profit levels π_0^* and π_1^*. Then we subtract π_0^* out of π_1^* to get the difference in the optimal profit $\pi_1^* - \pi_0^*$. Finally, we differentiate $\pi_1^* - \pi_0^*$ with respect to exogenous factors and thus get exogenous conditions for the substitution between money cost and time cost, as shown below in formula (14) – (18).

$$(14) \quad \frac{\partial(\pi_1^* - \pi_0^*)}{\partial P} > 0. \text{ there is a threshold value of } \bar{P} \text{ such that}$$

$$\text{if } P < \bar{P}, \text{ spend time processing information };$$

$$\text{if } P > \bar{P}, \text{ spend money hiring assistants.}$$

$$\textbf{(15)} \quad \frac{\partial(\pi_1{}^* - \pi_0{}^*)}{\partial A} > \mathbf{0}. \textit{ there is a threshold value of } \overline{A} \textit{ such that}$$

$$\textbf{if A} < \bar{A}, \textit{spend time processing information}$$

$$\textbf{if A} > \bar{A}, \textit{spend money hiring assistants.}$$

$$\textbf{(16)} \quad \frac{\partial(\pi_1{}^* - \pi_0{}^*)}{\partial r_w} < \mathbf{0}. \textit{ there is a threshold value of } \overline{r_w} \textit{ such that}$$

$$\textbf{if } r_w < \overline{r_w}, \textit{spend money hiring assistants.}$$

$$\textbf{if } r_w > \overline{r_w}, \textit{spend time processing information}$$

$$\textbf{(17)} \quad \frac{\partial(\pi_1{}^* - \pi_0{}^*)}{\partial r_k} < \mathbf{0}. \textit{ there is a threshold value of } \overline{r_k} \textit{ such that}$$

$$\textbf{if } r_k < \overline{r_k}, \textit{spend money hiring assistants}$$

$$\textbf{if } r_k > \overline{r_k}, \textit{spend time processing information}$$

$$(18-1) \quad \textit{when } \alpha \textit{ or } \beta \textit{ is high,} \quad \frac{\partial(\pi_1{}^* - \pi_0{}^*)}{\partial r_T} > 0.$$

$$\textit{there is a threshold value of } \overline{r_T} \textit{ such that}$$

$$\textbf{if } r_T < \overline{r_T}, \textit{spend time processing information}$$

$$\textbf{if } r_T > \overline{r_T}, \textit{spend money hiring assistants}$$

$$(18-2) \quad \textit{when } \alpha \textit{ or } \beta \textit{ is low,} \quad \frac{\partial(\pi_1{}^* - \pi_0{}^*)}{\partial r_T} < \mathbf{0}.$$

$$\textit{there is a threshold value of } \overline{r_T} \textit{ such that}$$

$$\textbf{if } r_T < \overline{r_T}, \textit{spend money hiring assistants}$$

$$\textbf{if } r_T > \overline{r_T}, \textit{spend time processing information}$$

3.3 Hypotheses

Summarizing results from the above theoretical model analysis, we have hypotheses in the following:

Hypothesis 1*: When land size and effective water are complementary inputs, information adoption increases with farm sales size. When land size and effective water are competitive, the direction of the effect of farm sales size is indefinite.*

From Table 4, we can see when the relationship between land size and effective water is complementary, the output price positively influences information adoption, and land price negatively influences information adoption. Reasonably assuming farmland follows the regular price-demand rule, we expect that land size has a positive effect on information adoption.

Combing the two effects, we see that larger farms in terms of sales size adopt more information, especially costly information. One reason is economies of scale. Given that the costs associated with accessing information and processing information are independent from farm size or output price, which is the usual case, information costs can be spread out over larger farmland or higher sales. Thus, information costs per acre or per dollar of sales go down with the increase in farmland size or sales, and so profits per acre or per dollar of sales go up. In addition to economies of scale, another advantage that larger farms have in adopting information is that they may have superior management skills that would allow them to acquire and process information more quickly (at lower time cost).

Hypothesis 2*: As water cost increases, there is more likely an increase in the adoption of the information that is associated with a high efficiency of irrigated water (high value of* h *) so that the elasticity of the marginal productivity of effective water is greater than 1. However, there is more likely a decrease in the adoption of the information that is* *associated with a lower efficiency of irrigated water (low value of h) so that the elasticity of marginal productivity of effective water is less than 1.*

Based on formulas (6), (7) , (10) and (11), as h increases, the elasticity of the marginal productivity of effective water is more likely to be greater than 1, or the effect of information on the marginal productivity of applied water is more likely to be negative. In turn, the effect of water cost on information adoption is more likely to be positive. Therefore, as water cost increases, there is more likely an increase in the adoption of the information that is associated with such high efficiency of irrigated water (higher value of h) that the elasticity of the marginal productivity of effective water is greater than 1.

Intuitively, what determines a farmer's yield is not the amount of applied water in irrigation, but the amount of effective water. The amount of effective water depends on both the amount of applied water and the proportion of effective water out of applied water. An increase in water cost reduces the amount of applied water[1], and thus potentially reduces the amount of effective water and yield.

However, the information that is associated with higher efficiency of applied water in irrigation and thus higher may reduce water loss so much as to eventually increase the amount of effective water and yield, even when the amount of applied water decreases. One example is shown in Figure 1. In the left graph, the applied water is 100 acre-feet, and the efficiency is 50%. Therefore, the effective water is 50 acre-feet. In the right graph, the applied water decreases to 90 acre-feet, but the efficiency increases to 67%. Therefore, the effective water increases to 60 acre-feet.

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[1] The increase in surface water cost may not influence the amount of surface water being applied, because surface water is not rationally in the market way, as shown in literature. But at least, the increase in pumping cost reduces the amount of ground water.

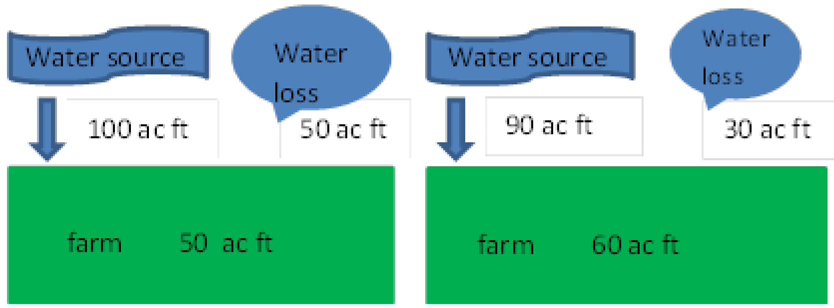

Figure 1 Applied water, efficiency and effective water

Therefore, the information that is associated with higher efficiency of irrigated water and thus higher elasticity (greater than 1) of the marginal productivity of effective water is increasingly adopted by farmers in order to reduce or even reverse the potential decrease in effective water and yield caused by higher water cost and reduced applied water. Water constraint reflected by higher water cost pushes farmers to adopt information that could substantially reduce water loss and improve the efficiency of irrigated water.

Hypothesis 3*: When the relationship between acreage and effective water is complementary, the adoption of information increases with the available time. When the relationship between acreage and effective water is competitive, the adoption of time-consuming information increases with the available time, while the adoption of time-conserving information decreases with the available time.*

The effect of $\mathbf{r_T}$ on information $\mathbf{k}$ as shown in Table 4 allows us to consider the effect of the time constraint on information adoption, since $\mathbf{r_T}$ is the shadow price of the available time. When $\mathbf{f_{12}}$ is positive, then $\frac{dk}{dr_T} > 0.$ This means when land size and effective water are complementary inputs, the shadow price of time has a negative effect on information adoption, or the available time has a positive effect on information adoption. However, when $\mathbf{f}_{12}$ is negative, the sign of $\frac{dk}{dr_T}$ is indefinite. Furthermore, when τ_0 is high, $\frac{dk}{dr_T}$ is more likely to be positive; when τ_0 is low, $\frac{dk}{dr_T}$ is more likely to be negative. This means when acreage and effective water are competitive inputs, the effect of the available time is indefinite. When the information is time-consuming, the available time has a positive effect on information adoption; when the information is time conserving, the available time has a negative effect.

Intuitively, when farmers have more time for farming, they are allowed to use more information especially more time-consuming information than when their time is limited. When farmers have less time for farming, they have to turn to more time-conserving information.

Hypothesis 4*: Farmers who need more time to adopt information tend to use less information.*

This hypothesis is directly interpreted from $\frac{dk}{d\tau_0} < \mathbf{0}$, as shown in Table 2 and Table 4. Intuitively, when farmers are slower in processing information and thus need more time to figure information out, they are restricted to using less information given the time constraint.

4. Data

To test the hypotheses from the theoretical model analysis, we use data of farmers' adoption of irrigation information and methods from the Economic Research Service (ERS), USDA. The data is based on USDA's Farm and Ranch Irrigation Surveys (FRIS) in 1998 and 2008, but processed and published by ERS as tabulations to protect respondent confidentiality. The FRIS has been conducted in eight years. For each FRIS, the Census of Agriculture publishes the survey data at state level. For 1998 and 2008 data, ERS published the data by state farm size group in cross-tab form. This farm size group level data is more specific than state level data, and provides more observations. Therefore, we use the data of FRIS in 1998 and 2008 from ERS.

In FRIS survey in both 1998 and 2008, farmers were asked, ”What are the sources of information you rely on for guidance in reducing irrigation costs or to conserve water used to for irrigation?” Respondents can choose multiple options from: extension agents or university specialists; government specialists; irrigation equipment dealers; irrigation district or water supplier; private irrigation specialists or consultants; media reports/press; neighboring farmers; electronic information services (an option available only in 2008); or other information sources.

Farmers were also asked, “How did you decide when to apply water?” Respondents could pick any of the following: condition of crop by observation; feel of the soil; soil moisture sensing devices; commercial scheduling services; media reports on crop water needs; water delivered in turn; calendar schedule; computer simulation models; plant moisture sensing (an option available only in 2008); neighbor practices (an option available only in 2008); or other practices.

Summarizing responses from these two questions above, ERS published nine tabulations about “sources of information used to reduce costs or conserve water”, and 13 tabulations about “methods of deciding when to apply irrigation water”, including above 11 options and two aggregate categories: ‘most water-management intensive and water-conserving means’, and ‘any (one or more) irrigation scheduling technique’. The aggregate category ‘most water-management intensive and water-conserving means’

means any (one or more) of the four methods: soil moisture sensing devices; commercial scheduling services; computer simulation models; plant moisture sensing. Each cross-tab shows the numbers of farms adopting one particular method or one particular source of information by farm size category and by state.

There are four farm size categories based on farm sales value from Census of Agriculture in the previous year. By sales value, farms are classified into four size categories: small (< $100,000), medium ($100,000 to <$250,000), large ($250,000 to < $500,000), and very large (>=$500,000). ERS provided data for the four farm size classes for the 17 contiguous westernmost U.S. states. Therefore, for each scheduling method or each source of information, the data is farm size group level and the number of observations is 136 (4 farm size category × 17 western states × 2 years). Table 5 shows the total number of farms (expanded data) involved in the 136 observations and their distribution by farm sales size class. There is a higher proportion of very large farms in 2008 than in 1998. Large and very large farms account for 19.2-24% of total irrigated farms, but account for 66.1-79.1% of total water applied.

Table 5 Distribution of farms and irrigated water applied by farm sales class in 17 western states

	1998				2008			
	small	medium	large	very large	small	medium	large	very large
Percent of farms	65.2	15.6	9.7	9.5	62.7	13.0	9.0	15.3
Percent of water applied	18.3	15.6	17.8	48.4	10.7	10.2	13.2	66.0
Cumulative percent of farms	65.2	80.8	90.5	100.0	63.0	76.0	85.0	100.0
Cumulative percent of water applied	18.3	33.9	51.7	100.0	10.7	20.9	34.1	100.0
All farms								
Total number of farms	147,090				155,846			
Total water applied (Acre Feet)	76,183,600				71,850,586			
Acre Feet water applied/farm	518				461			

This table is expanded data, which is the sample data value multiplied by the total FRIS weight. The sample size is 23,567 in 1998 and 33,085 in 2008. Numbers may not add up exactly due to rounding. Source: USDA, ERS.

Since ‘other information sources’ and ‘other practices’ for scheduling irrigation are not specific, we drop these cross-tabs. We keep the aggregate category ‘most water-management intensive and water-conserving means’, because it shows the overall adoption of management-intensive methods. Finally, we use data in tabulations of eight sources of information and 11 scheduling methods.

Because the data for information adoption is not individual farm level but aggregate group level, we use adoption rates within each group. To calculate adoption rates, we divide the number of farms adopting particular information in each size group of each state by the total number of irrigated farms in the same group. As mentioned above, the number of farms adopting particular information is available by farm size category and by state. The number of total irrigated farms is also available by farm size category and by state.

Before modeling these calculated adoption rates, we first discuss descriptive statistics as shown in Tables 6 – 9. In additional to adoption rates for individual information, the sum of adoption rates across different information is also presented. The sum of adoption rates across ten different scheduling methods (not include the aggregate category ‘most water-management intensive and water-conserving means’) represents the average number of methods being adopted. The sum of adoption rates across nine different sources of information represents the average number of information sources that farmers rely on. We denote the sum of adoption rates across different scheduling methods as the index of scheduling methods, and denote the sum of adoption rates across different sources of information as the index of information sources. Therefore, higher values of the indices represent that farmers adopt more scheduling methods or more sources of information.

Table 6 Methods of deciding when to apply irrigation water in 2008
(values are percentage yes responses)

Scheduling methods	Small	Medium	Large	Very Large
Condition of Crop by Observation	65	84	76	85
Feel of the Soil	36	50	46	54
Media Reports on Crop Water Needs	4	19	24	19
Water Delivered in Turn by the Irrigation Organization	18	9	8	7
Calendar Schedule	30	24	18	22
Neighbor Practices	9	5	6	4
Soil-Moisture Sensing Devices	5	12	16	20
Commercial-Scheduling Services	7	7	13	15
Computer Simulation Models	1	1	1	2
Plant Moisture Sensing	1	3	5	4
Most Water-Management Intensive and Water-Conserving Means	10	21	27	33
Sum of methods used per irrigated farm	176	214	214	233

Table 7 Methods of deciding when to apply irrigation water in 1998
(values are percentage yes responses)

scheduling methods	Small	Medium	Large	Very Large
Condition of Crop by Observation	64	81	82	84
Feel of the Soil	36	42	47	53
Media Reports on Crop Water Needs	2	9	12	14
Water Delivered in Turn by the Irrigation Organization	15	10	6	6
Calendar Schedule	22	12	20	18
Neighbor Practices	n.a.	n.a.	n.a.	n.a.
Soil-Moisture Sensing Devices	4	9	16	25
Commercial-Scheduling Services	1	5	12	14
Computer Simulation Models	1	1	1	3
Plant Moisture Sensing	n.a.	n.a.	n.a.	n.a.
Most Water-Management Intensive and Water-Conserving Means	5	14	26	35
Sum of methods used per irrigated farm	145	168	196	217

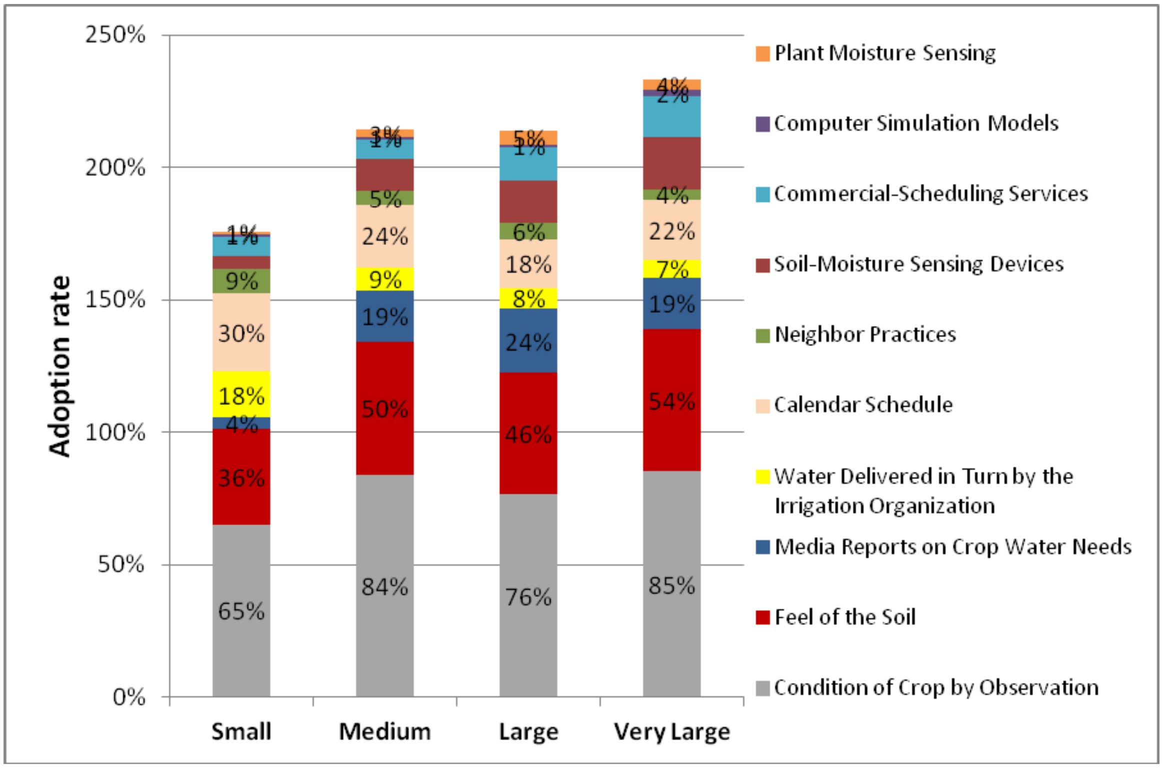

Figure 2. Adoption rates of scheduling methods by farm size in 2008

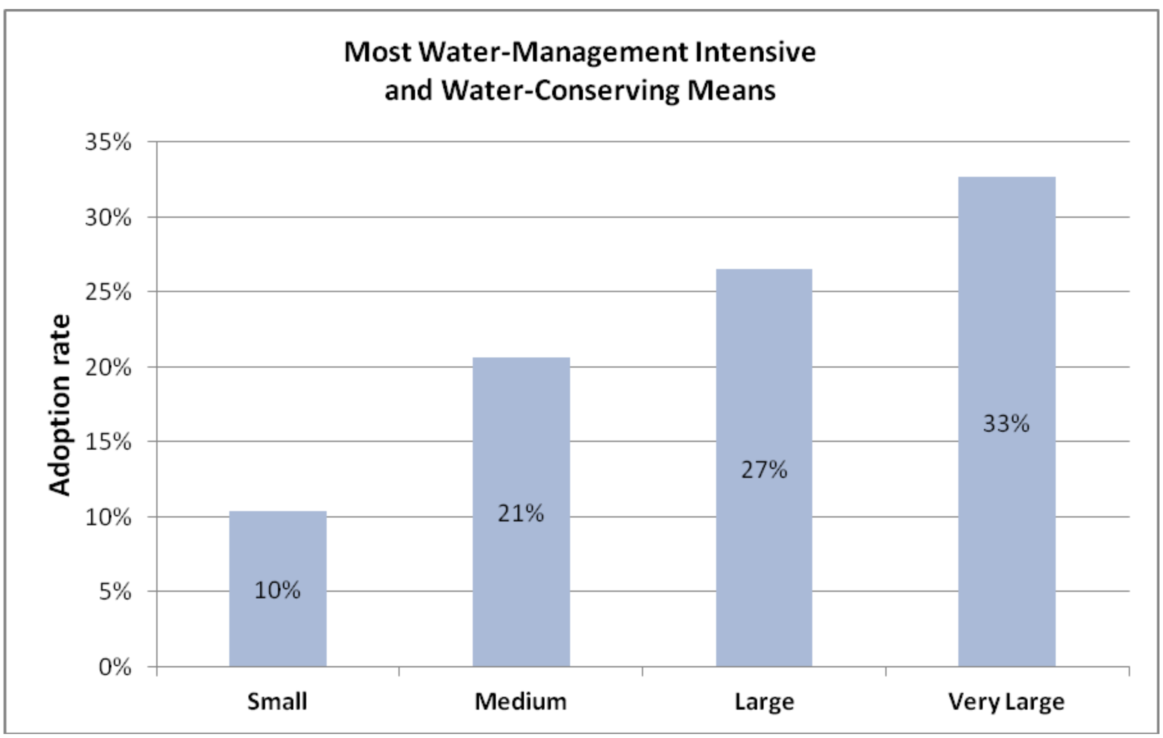

Figure 3. Adoption rates of 'most water-management intensive and water-conserving means' by farm size in 2008

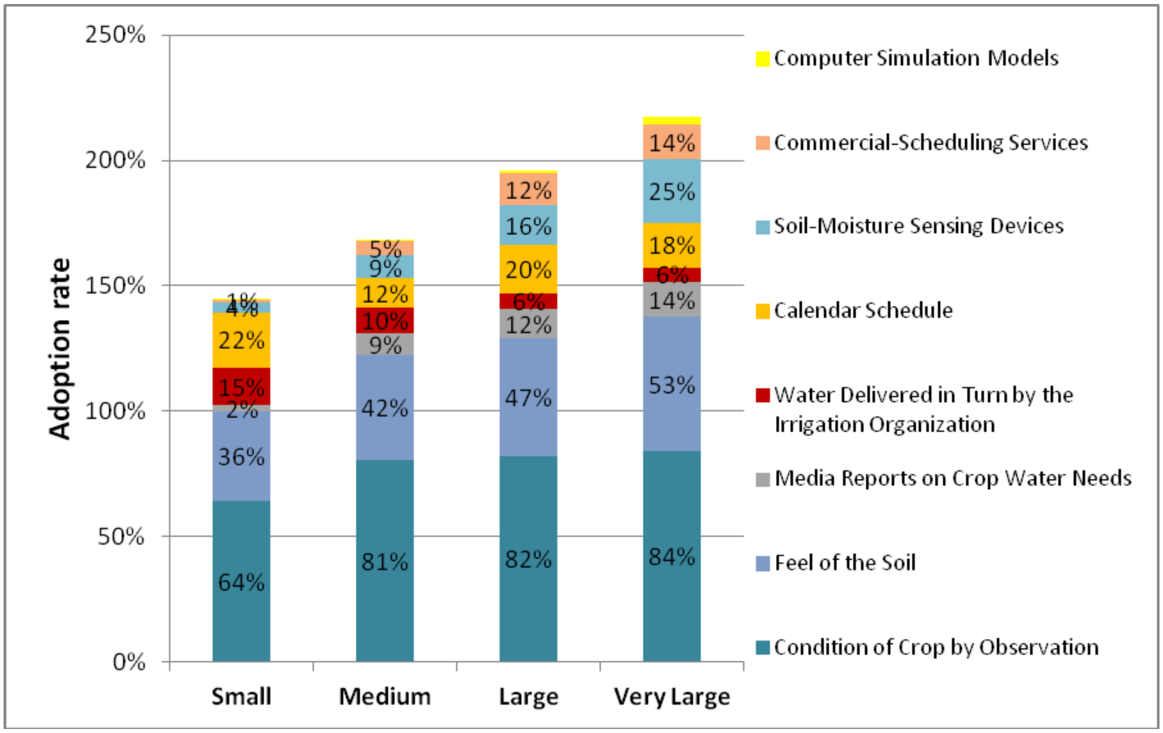

Figure 4. Adoption rates of scheduling methods by farm size in 1998

From Table 6 and Table 7, we can see:

1) The sum of adoption rates across scheduling methods, which represents the average number of adopted methods, increases with farm size. That is, larger farms adopt more methods, as shown in Figure 2 and Figure 4. 2) For most methods, adoption rates increase with farm size, with three exceptions: “water delivered in turn by the irrigation organization”, “calendar”, and “neighbor practices”. Smaller farms have higher adoption rates of these three methods.

3) Regardless of farm size, adoption rates of computer simulation models are generally low.

4) The adoption rates of each modern, management-intensive method (“soil-moisture sensing devices”, “commercial-scheduling services”, “plant moisture sensing”) and the adoption rates for the aggregate category “most water-management intensive and

water-conserving means" (as shown in Figure 3), increase with farm size at higher rates than the adoption rates of conventional, less management-intensive methods (such as "condition of crop by observation", "feel of the soil", and "media reports on crop water needs").

Table 8 Sources of information used to reduce costs or conserve water in 2008 (values are percentage yes responses)

sources of information	Small	Medium	Large	Very Large
Extension Agents or University Specialists	21	38	35	40
Government Specialists	11	19	21	20
Irrigation Equipment Dealers	12	32	30	41
Irrigation District or Water Supplier	17	11	12	12
Private Specialists or Consultants	11	32	27	42
Media Reports or Press	10	15	15	15
Neighboring Farmers	33	29	30	31
Electronic Information Services	5	17	13	18
Total number of sources of information per irrigated farm	120	192	183	219

Table 9 Sources of information used to reduce costs or conserve water in 1998 (values are percentage yes responses)

sources of information	Small	Medium	Large	Very Large
Extension Agents or University Specialists	24	32	41	37
Government Specialists	11	17	26	19
Irrigation Equipment Dealers	18	32	45	42
Irrigation District or Water Supplier	17	13	14	14
Private Specialists or Consultants	3	13	23	28
Media Reports or Press	9	20	21	18
Neighboring Farmers	36	43	44	41
Electronic Information Services	n.a.	n.a.	n.a.	n.a.
Total number of sources of information per irrigated farm	119	170	213	199

Table 8 and Table 9 provide a brief descriptive statistics about sources of information.

1) In general, the average number of sources of information adopted increases with farm size. Larger farms rely on information from more sources. However, the

average number of information sources being relied on is not monotonically increasing by farm size (as shown in Figure 5 and Figure 6). However, this is only univariate analysis and is not conclusive. In the following multivariate regressions, we control other influential factors. 2) Larger farms have higher adoption rates of information from any source except "irrigation district or water supplier" and "neighbors".

3) The adoption of information from private sources (such as "irrigation equipment dealers" and "private specialists or consultants") increases with farm size at higher rates than the adoption of information from public sources (such as "extension agents or university specialists", "government specialists", and "media reports or press").

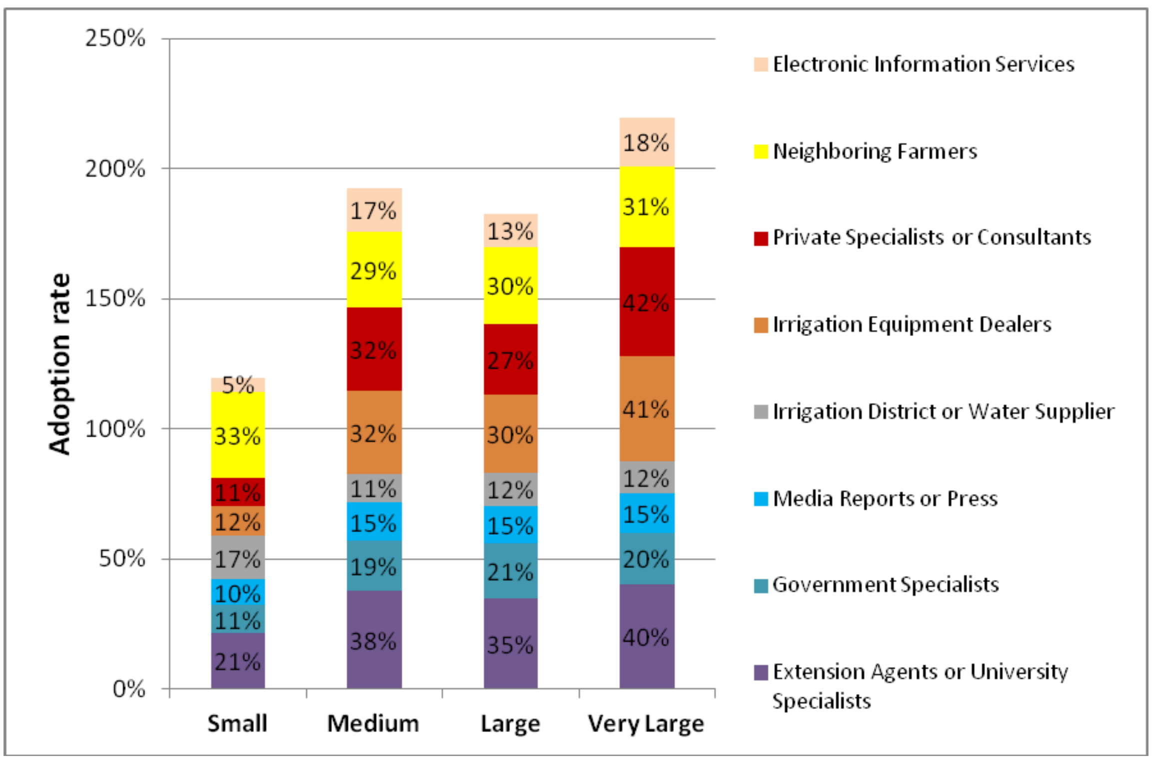

Figure 5. Adoption rates of information sources, by farm size in 2008

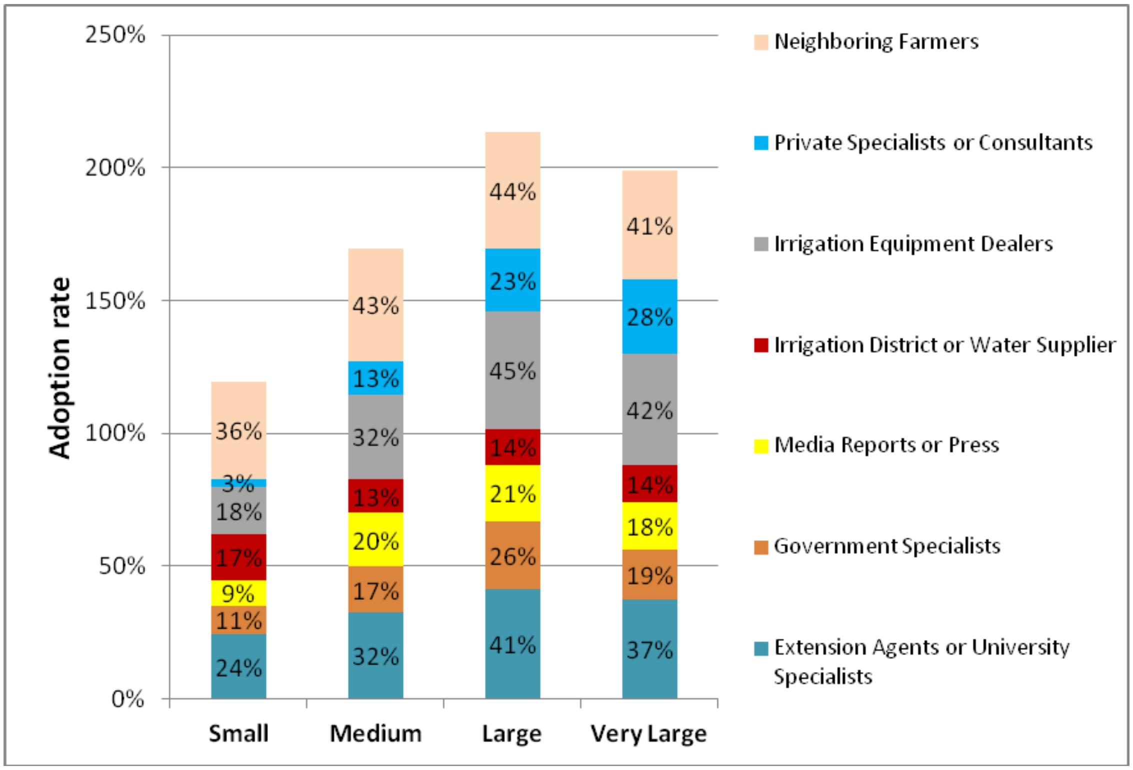

Figure 6. Adoption rates of information sources, by farm size in 1998

5. Empirical Model

A logit model is applicable to a binary choice of information adoption at individual farm level. As shown below, the binary dependent variable equals to 1 if farms adopt information, and equals to 0 if farms do not adopt information. X is a collection of explanatory variables for information adoption. ε is the error term with standard logistic distribution.

$$y^* = \beta x + \varepsilon \qquad y = \begin{cases} 0, & if\ y^* < y^*_0 \\ 1, & if\ y^* > y^*_0 \end{cases}$$

However, the data for this study are not individual farm level but farm size group level, and the variable we use for information adoption is not binary but the adoption rate. Therefore, we use an empirical model as shown in formula (19). The equation in formula

(19) follows from the above logistic model and treats the adoption rate to be the probability for farmers to adopt information, as shown in formula (20).

$$(19) \quad ln\frac{adoption\ rate}{1-adoption\ rate} = ln\frac{\mathrm{P(y=1|x)}}{\mathrm{P(y=0|x)}} = ln\frac{\frac{e^{\beta x}}{1+e^{\beta x}}}{1-\frac{e^{\beta x}}{1+e^{\beta x}}} = \ln(e^{\beta x}) = \beta x$$

$$(20) \quad \textbf{adoption rate} = \mathbf{P(y=1|x)} = \mathbf{P}(y^* > \ \mathbf{0}|\mathbf{x}) = P(\varepsilon > -\beta x|\mathbf{x}) = \frac{e^{\beta x}}{1+e^{\beta x}}$$

As stated in the data section, we created an index of scheduling methods and an index of information sources. Because the index is the sum of adoption rates, the empirical equation in formula (19) is not applicable to the indexes. Therefore, we use a simple linear equation to examine the indexes, as shown in formula (21). For the indexes, we use the same explanatory variables as we use for individual information in formula (19).

$$the\ index = \beta x + \ \varepsilon \qquad (21)$$

Moreover, farmers' adoption of different types of information could be correlated. Seemingly unrelated regression is applicable to systems of regression equations and could potentially increase the efficiency of estimation. However, the existence of missing values makes the data unbalanced. While dealing with unbalanced data, seemingly unrelated regression deletes all observations with any missing value, and thus decreases the number of observations and the efficiency of estimation. For the data in this paper, seemingly unrelated regression reduces the number of observations to less than half of the original sample size. Some of the missing data is random, while other missing data is because some information was not surveyed in 1998 and thus only has available data in 2008. Therefore, we use OLS to estimate the empirical models.

We tested for heteroskedasticity and do corresponding correction if heteroskedasticity exists.

6. Variables

6.1 Dependent variables

As stated in the section of empirical model, $\frac{\ln(adoption\ rate)}{1 - adoption\ rate}$ is used as a dependent variable for each individual method or information source. In additional, we use an index of scheduling methods and an index of information sources as dependent variables.

The reason we are interested in these two indexes is that the indexes measure the diversity of information adoption. Irrigation information in the context of this paper is one input that is not divisible. In other words, we know how many farms use particular information, but we do not know how much irrigated farm land or how much irrigated water the particular information is applied to. Therefore, one of our areas of focus is the number of sources of information or the number of scheduling methods.

6.2 Explanatory variables

1. Farm Sales Size:

Following Hypothesis 1, we use farm sales size as one explanatory variable. The data we use to measure information adoption is from cross-tabs by farm sales size category and by state. Accordingly, three dummy variables for farm sales size are used: dummy_medium, dummy_large, and dummy_very_large. Reference size is small.

2. Year:

We use the data of information adoption at two time points: 1998 and 2008. To catch the possible changes in adoption over time, a dummy year variable is used, which equals to 0 if the year is 1998, and equals to 1 if the year is 2008.

3. Water cost:

i. Calculation.

Based on Hypothesis 2, water cost is expected to influence irrigation information adoption. Water applied in irrigation is composed of surface water and ground water. Further, surface water is composed of on-farm surface water and off-farm surface water, of which off-farm surface water has a purchasing cost. The cost associated with ground water is pumping cost.

To get the combined water cost, we first use average purchased water cost ($ per acre-foot) for farms using off-farm surface water, and off-farm surface water applied (acre-feet) to get total purchasing cost by farm size category and by state. Then we divided it by total water applied (acre-feet) to get the average purchasing cost ($ per acre-foot) of total water at farm size group level. Similarly, dividing total pumping cost by total water applied (acre-feet), we get state level average pumping cost ($ per acre-foot) of total water. For the total pumping cost, we use energy expense for on-farm pumping of irrigation water by state. Thus, adding these two average cost, we get the combined average cost of total water.

Note, that the average purchasing cost ($ per acre-foot) of total water is farm size group level, while the average pumping cost ($ per acre-foot) of total water is state level. Therefore, the differences in the combined average cost of total water across different farm size groups in one state are only from the part of purchasing cost, while the differences in the combined average cost of total water across different farm size groups in different states are from both purchasing cost and pumping cost. Moreover, to adjust for inflation and get comparable real water cost, we adjust the combined average cost for total water by using GDP price deflator, which is 0.79 in 1998 and 0.99 in 2008 with 2009 index number =1. Finally, we use ln of deflated water cost to obtain residuals that are more likely to be symmetrically distributed and homoscedasticity.

ii. Data Sources for the Calculations Above.

a. ERS

From the FRIS tables summarized by ERS, USDA, we get data to calculate the average purchasing cost for total water. The data includes: 1) the data measuring the average purchased water cost ($ per acre-foot) for farms using off-farm surface water, 2) the data for off-farm surface water applied (acre-feet), and 3) the data for total water applied (acre feet). These data are available by farm size category and by state.

b. Census of Agriculture

Data involved in calculating the average pumping cost of total water, is from FRIS tables presented in 1998 and 2008 Census of Agriculture. The data includes: 1) Data of energy expense for on-farm pumping of irrigation water, and 2) data of total water applied (acre-feet). These data are available only by state. Note that total water applied (acre feet) by all farm size groups in one state from FRIS tables presented in 1998 and 2008 Census of Agriculture is not exactly same with the sum of total water applied (acre feet) of 4 farm size groups from FRIS tables summarized by ERS, possibly because these data are aggregated in different levels. However, the difference is negligible.

c. USDC

Data of GDP price deflator is from Bureau of Economic Analysis, USDC.

4. *Climate*:

Climate conditions, especially drought, are expected to influence irrigation practices. The increasing occurrence of drought heightens the demand for irrigated water, and simultaneously reduces water supply. If water cost rationally reflects water supply and demand, the effect of drought should be contained in the effect of water cost.

However, water cost, at least the variable of water cost we use in this research, seldom reflects real water supply and demand. As discussed above, the variable representing water cost is composed of two parts: the purchasing cost for surface water, and the pumping cost for ground water. The price of surface water is not usually determined by market supply and demand. Additionally, the pumping cost for ground water is more about energy cost, which is beyond water supply or demand, even though the pumping cost does reflect the pumping depth and therefore indicates water supply to some extent.

Therefore, the drought condition is added into the empirical examination to provide additional information that the water cost variable cannot offer about water supply and demand. To be cautious, we will also check the correlation between the variables for drought and water cost, and also do a multicollinearity diagnostic.

Specifically, we use the Palmer Modified Drought Index (PMDI) from the National Climatic Data Center, National Oceanic and Atmospheric Administration. PMDI measures the stock of soil moisture and the data is available at state-level by month. The value of PMDI ranges from -7 to 7. Negative values indicate drought, while positive values indicate moisture. Furthermore, there are different degrees of severity of drought: normal (0 to -0.5), incipient drought (-0.5 to -1.0), mild drought (-1.0 to -2.0), moderate drought (-2.0 to -3.0), severe drought (-3.0 to -4.0), and extreme drought (greater than -4.0). Similar rules are applicable to positive values to measure the severity degree of moisture. Based on average monthly PMDI in the previous five years, we create two variables DRY and WET to separately catch the possible effects of drought and moisture. DRY takes the PMDI value if the PMDI<0, otherwise DRY is equal to 0; WET equals to the PMDI value if the PMDI>0, otherwise WET is equal to 0.

As stated in previous paragraphs, the drought condition produces effects through water supply and demand. Therefore, expected effects of the variables DRY and WET follow Hypothesis 2, which is about the theoretical effect of water cost (water cost that completely reflects the supply and demand). According to Hypothesis 2, the variable DRY is expected to have a positive effect on the adoption of management-intensive information, but a negative effect on the adoption of less management-intensive information. The coefficient of the variable WET is expected to have the opposite sign of the variable DRY.

5. Residence Off Farm:

Based on Hypothesis 3, farmers' available time is expected to influence information adoption. We use farmers' residence off farm to proxy their available time. Farmers who reside off farm may have non-farming jobs or at least need to spend time to arrive farms. Therefore, they have less time available to spend on farming and information adoption.

From 1998 and 2008 Census of Agriculture, the numbers of farms whose farmers reside off farm are available. Dividing these numbers by the numbers of total farms in each farm size category in each state, we get the percentage of farms whose farmers reside off farm.

6. Demographic characteristics:

Hypothesis 4 tells us farmers who need more time to adopt information are likely to use less information. In addition, farmers' age, race, or origin could affect the time they need to process information. For farmers who are older, non-white, or Hispanic, irrigation methods or information may not be designed with them in mind, or be provided in their native languages. Additionally these farmers may be more isolated, and thus it may take more time for these farmers to acquire and process information. Therefore, farmers who are older, non-white, or Hispanic may adopt less information, especially those forms of information that are time-consuming.

Over 65:

In 1998 and 2008 Census of Agriculture, total farms are classified into eight different age groups for each farm size category in each state. Here we pick two age groups: 65-69 years old and 70 years old and over, add the numbers of farms falling in these two groups, and then divide this sum by the number of total farms to get the percentages of farms whose farmers belong to age groups over 65 for each farm size group in each state.

Non-white.

In 1998 and 2008 Census of Agriculture, total farms are classified into four different race groups for each farm size category in each state. Here we pick three groups: American Indian or Alaska Native, African American, and other, add the numbers of farms falling in these three groups, and then divide this sum by the number of total farms to get the percentages of farms whose farmers' race are American Indian or Alaska Native, African American, or other for each farm size group in each state.

Hispanic.

From 1998 and 2008 Census of Agriculture, the numbers of farms whose farmers are of Spanish, Hispanic, or Latino origin are available. Here we divide these numbers by the numbers of total farms in each farm size category in each state to get the percentages of farms whose farmers are Hispanic.

Table 10 shows descriptive statistics for explanatory variables (except dummy variables). All these variables have wide ranges. Water cost ranges from $4.69 to $79.01 per acre-foot. Drought condition varies from -3.86 (severe drought) to 5.53 (extreme moisture). The proportions of farms whose principal farmers live off farm or are non-white have minimum value of 0-7.6%, and maximum values of 55% or even almost 60%. The proportions of farms whose principal farmers are over 65 or Hispanic have minimum value of 0.1-6.7%, and maximum values of 33-38%.

Moreover, for some of these variables, their variations across farm size groups are shown through Figure 7 -11. Generally, smaller farms have higher water cost, and more likely to have old, non-white, and Hispanic farmers. Both small and very large farms are more likely to have farmers living off farm.

Table 10 Descriptive statistics for explanatory variables (except dummy variables)

Variable	variable description	Obs	Mean	Std. Dev.	Min	Max
lnwatercost	Ln of deflated water purchasing cost and pumping cost ($ per acre feet)	136	3.162	0.637	1.550	4.370
	Antilog of lnwatercost ($ per acre feet)	136	28.414	17.194	4.690	79.010
wet	0 or positive value of average monthly PMDI in previous 5 years	136	1.076	1.411	0.000	5.530
dry	0 or negative value of average monthly PMDI in previous 5 years	136	-0.423	0.791	-3.860	0.000
residence off farm	Proportion of farms whose principal farmers live off farm to total irrigated farms	136	0.232	0.101	0.076	0.552
over65	Proportion of farms whose principal farmers are over 65 years old to total irrigated farms	136	0.234	0.068	0.067	0.378
non_white	Proportion of farms whose principal farmers are American Indian, African American, or other non−white to total irrigated farms	136	0.035	0.059	0.000	0.586
hispanic	Proportion of farms whose principal farmers are Hispanic to total irrigated farms	136	0.032	0.045	0.001	0.326

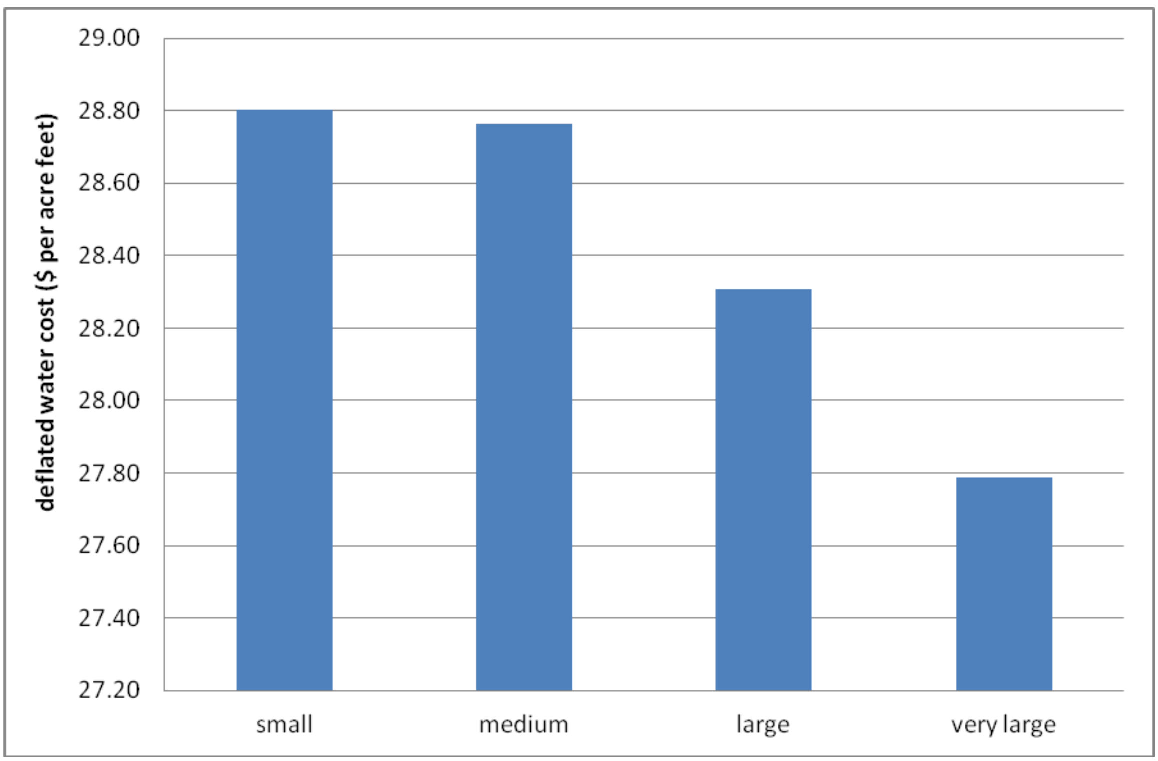

Figure 7 Water cost ($ per acre feet) by farm sales size category

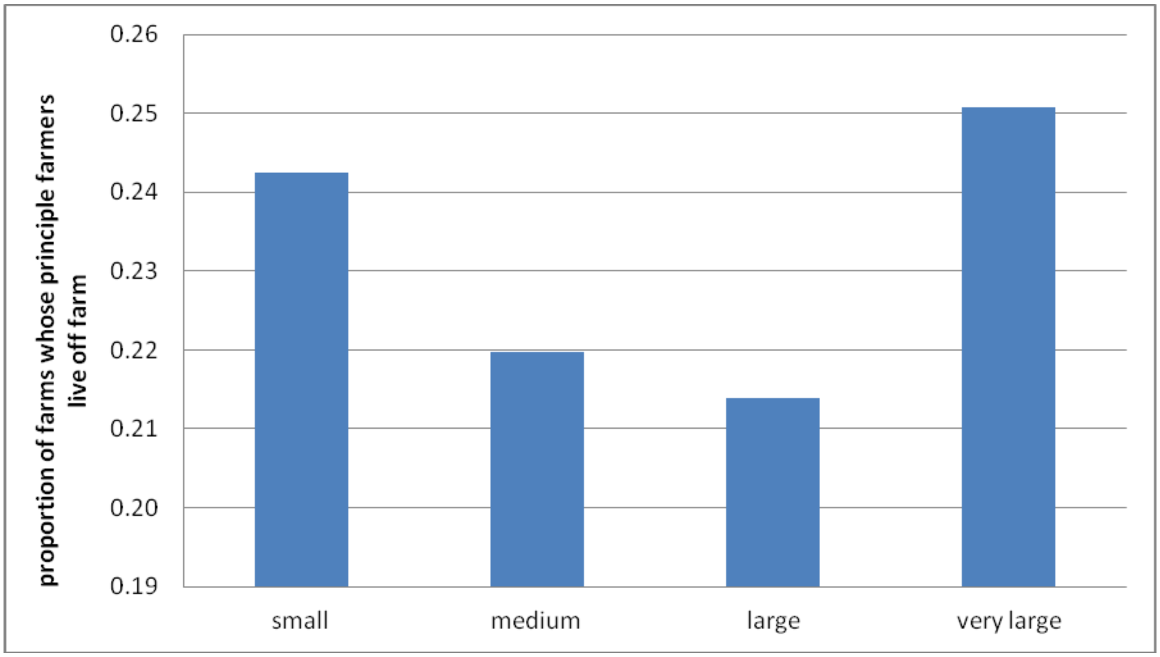

Figure 8 Proportion of farms whose principal farmers live off farm by farm sales size category

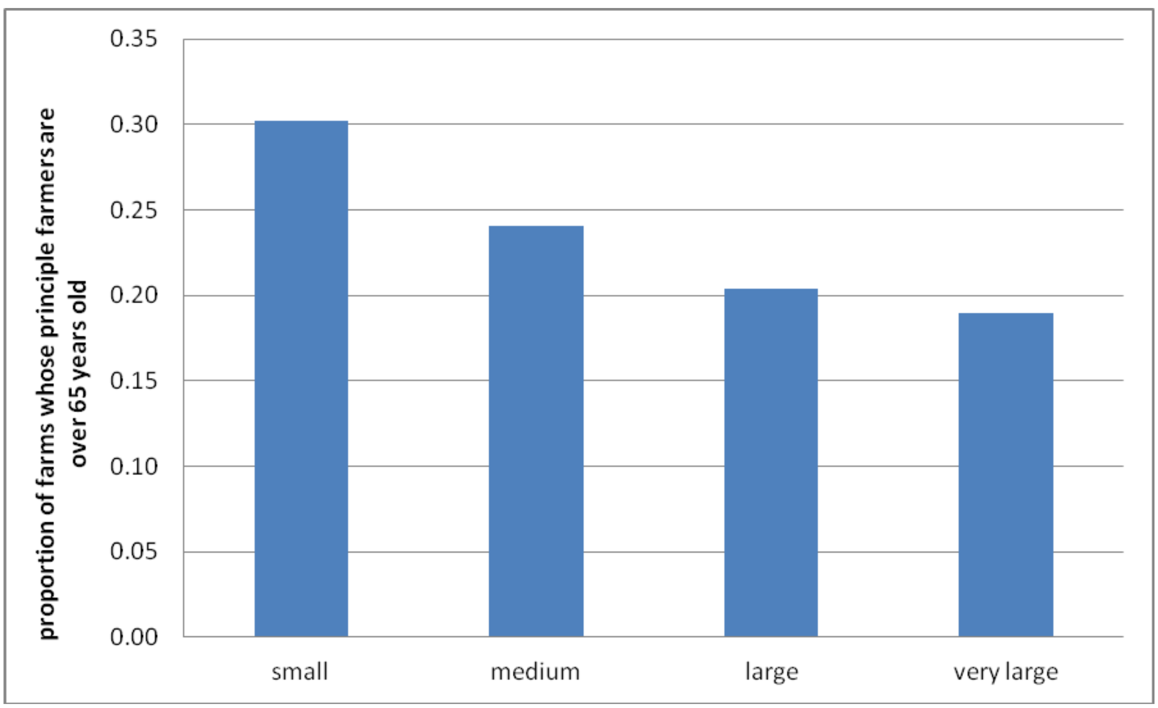

Figure 9 Proportion of farms whose principal farmers are over 65 years old by farm sales size category

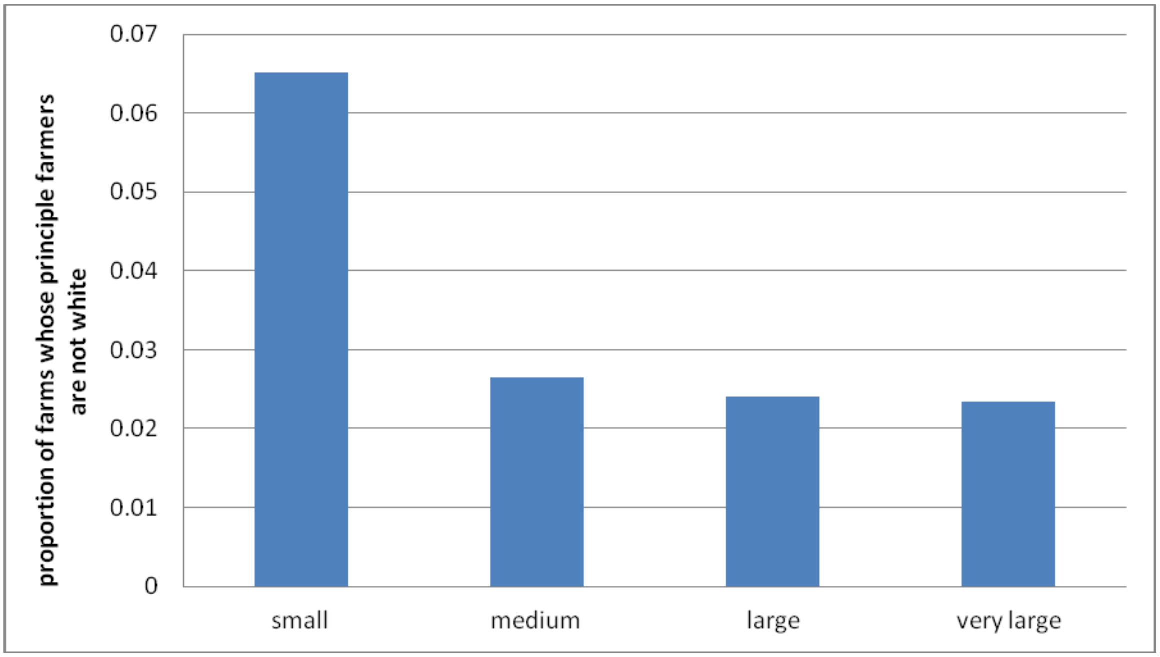

Figure 10 Proportion of farms whose principal farmers are not white by farm sales size category

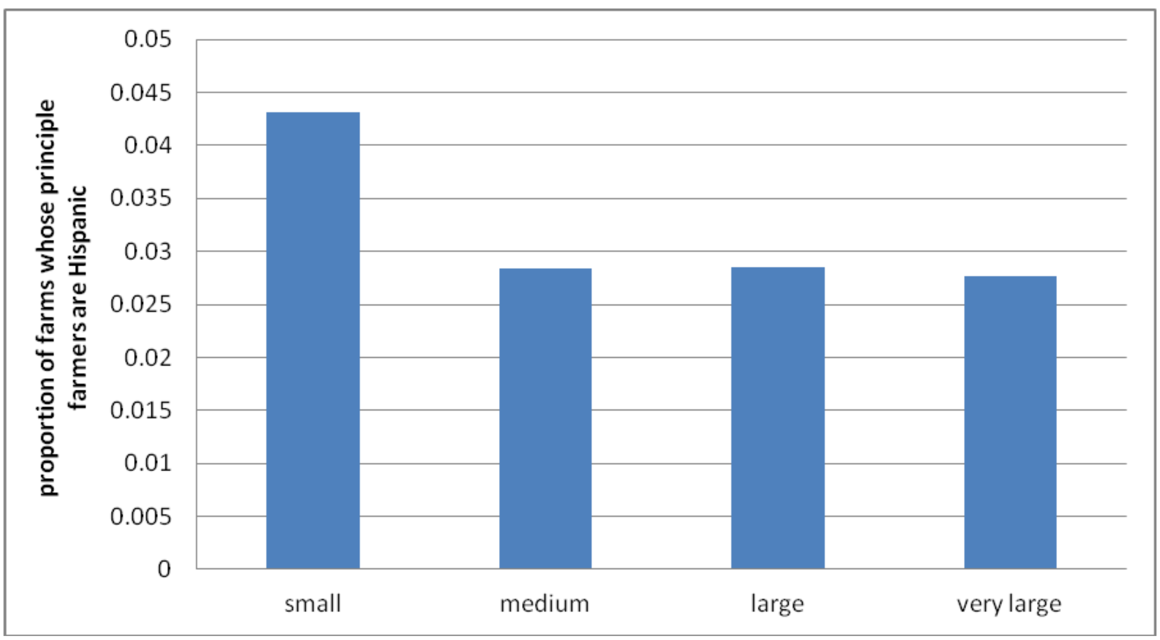

Figure 11 Proportion of farms whose principal farmers are Hispanic by farm sales size category

7. Estimation Results

7.1 The number of types of information

Regression results for these two indexes are shown in Table 11. Based on both the White's test and the Breusch-Pagan test, heteroskedasticity exists for both models. Therefore, the results are from the regression with robust standard error term, in which standard errors are adjusted by using the heteroscedasticity consistent covariance.

1. Farm size

All three dummy variables for farm sales size have positive coefficients in both of the index models, and the coefficients are statistically significant. Larger farms adopt more scheduling methods and more sources of conserving information.

Table 11 The number of methods and the number of information sources being adopted

	index of scheduling methods	index of sources of conserving methods
Intercept	1.833(7.77)	1.258(4.95)***
dummy_medium	0.12(1.7)*	0.409(5.03)***
dummy_large	0.184(2.07)**	0.58(5.33)***
dummy_very_large	0.35(3.83)***	0.728(7.93)***
dummy_year	0.186(2.02)**	-0.004(-0.04)
lnwatercost	0.045(0.95)	0.075(1.25)
dry	-0.046(-1.1)	0.002(0.04)
wet	-0.038(-1.84)*	-0.048(-1.89)*
Residence off farm	0.16(0.56)	0.07(0.19)
over65	-1.505(-2.73)***	-0.135(-0.21)
non white	0.055(0.19)	-0.184(-0.34)
Hispanic	0.467(0.72)	-1.264(-1.71)*
estimation method	regression with robust error term	regression with robust error term
observations	136	136
R-Square	0.43	0.50
White's Test	72.7	84.08*
Breusch-Pagan	18.14*	18.73*

T-statistics in parentheses;
significance at 1%, 5% and 10% level are denoted by ***, **, and *, respectively

Comparing the coefficients of farm size variables between the two index models, we observe that farm size has more influences on the number of sources of conserving information than farm size has on the number of scheduling methods. The differences in the number of sources of conserving information across different farm size groups are larger than the differences in the number of scheduling sources across different groups.

Possible reasons could be: 1) compared with sources of conserving information, scheduling methods are more like necessities. Scheduling methods are necessary for irrigation and farming, while sources of conserving information are options for possible lower cost and higher profits. Just as the differences in necessities across different income groups are less than the differences in other demand, the differences in the amount of scheduling methods are less than the differences in the amount of sources of conserving information across different farm size groups. 2) the substitution among different scheduling methods are higher than that among different sources of conserving information. The new information gained from additional scheduling methods could be less than the new information gained from additional sources. Even with affordability, large farms do not need to adopt much more scheduling methods.

2. Water cost

Water cost has positive coefficients in both models but the coefficients are not significant.

3. Climate

The variable WET has significant negative coefficients in both models. The relative wet condition in the previous five years relieves the pressure on the irrigated water, and so the need for farmers to conserve water is less pressing. Consequently, farmers' demand for irrigation information decreases. Farmers use fewer scheduling methods and rely on fewer sources for information.

The coefficients of the wet condition on the number of scheduling methods being adopted and on the number of information sources being relied on are respectively 0.04 and 0.05. Because the empirical model for the indexes is a simple linear equation in formula (21), these coefficients can be directly translated into the marginal effects of the wet condition. The predicted values of the number of scheduling methods being adopted and the predicted values of the number of information sources being relied on could also be directly calculated from formula (21). As shown in Figure 12, for every 0.5 increase in the positive values of the PMDI index, the number of scheduling methods being adopted reduces 0.019 (other variables take their mean values).

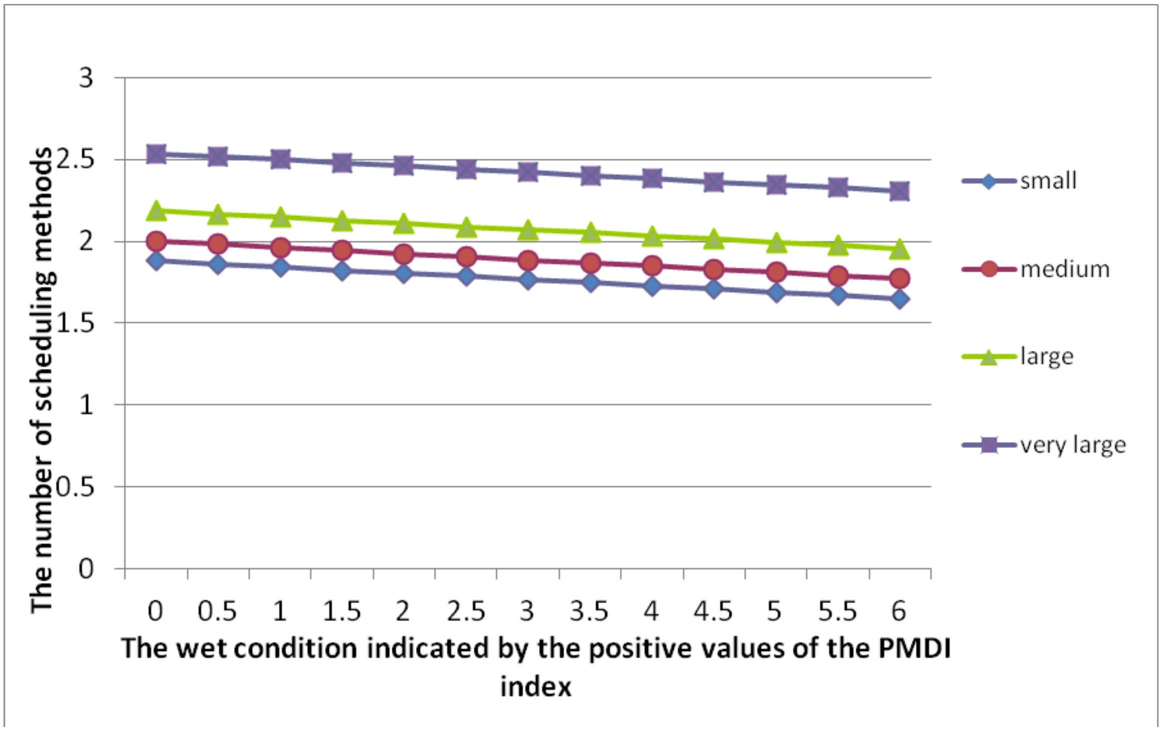

Figure 12 The effects of the wet condition on the number of scheduling methods being adopted, by farm sales size, 2008.

4. Demographic characteristics

The variable Over65 has negative coefficients in both models but is significant only in the model of index of scheduling methods. With limited technical capacity, older farmers over 65 years old probably have difficulty in using modern scheduling methods, or need spend more time to use them. Given the limitations of both technical capacity and the available time for farming, older farms over 65 years old probably adopt less scheduling methods.

Furthermore, the coefficient of the variable Over65 is -1.51 in the equation of the index of scheduling methods. As shown in Figure 13, for every three percentage-point increase in the portion of farmers over 65 years old, the number of scheduling methods being adopted declines by 0.045 (other variables take their mean values).

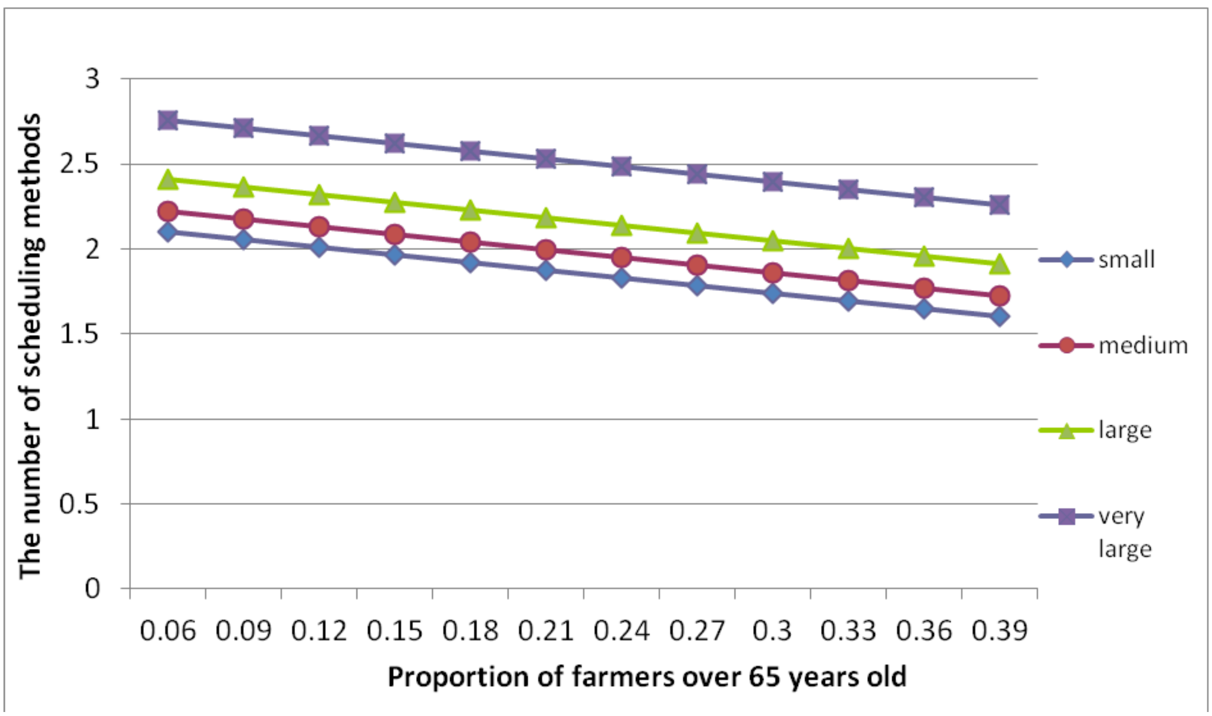

Figure 13 The effects of farmers' age structure on the number of scheduling methods being adopted, by farm sales size, 2008.

The variable Hispanic has a significant negative effect on the number of information sources, which indicates Hispanic farmers rely on fewer sources for information. For every one percentage-point increase in the portion of Hispanic farmers, the number of information sources that farmers rely on would reduce 0.013.

7.2 Individual category regressions

1. Farm size

For any scheduling method or source of conserving information, at least one of the three farm size variables significantly positively relates with the adoption, with three exceptions as follows:

For “water delivered in turn by the irrigation organization” and “neighbor practices”, adoption rates significantly decreases with farm size. Smaller farms are more likely to rely on water delivered in turn by the irrigation organization as their water source. Only when they receive water from the irrigation organization, they can irrigate. Therefore, for smaller farms, when to irrigate is more likely to depend on when the irrigation organization delivers water.

Smaller farms are also more likely to follow neighbors’ practices to schedule irrigation than larger farms are. This may because larger farms have superior irrigation management skills and smaller farms attempt to copy their practices.

For “calendar schedule”, the effects of farm size on the adoption rate are not significant. Calendar scheduling is one of the most conventional methods to schedule irrigation. It is almost free, and requires little time and little technical capacity. Thus, there is little cost to use calendar as a reference for scheduling irrigation, and it is technically easy for any farm to adopt. There is no additional benefit for larger farms to obtain, and there is also no additional technical barrier that prevents smaller farms to use calendar. Therefore, farm size does not matter for the adoption of “calendar schedule.”

Table 12 Farmers' demand for scheduling methods

	Condition of Crop by Observation	Feel of the Soil	Media Reports on Crop Water Needs	Water Delivered in Turn by the Irrigation Organization	Calendar Schedule	Neighbor Practices
Intercept	-0.105 (-0.2)	0.322 (0.72)	-6.168 (-5.74)***	0.497 (0.56)	-0.735 (-1.3)	-0.065 (-0.05)
dummy_medium	0.638 (4.06)***	0.042 (0.26)	0.69 (2.04)**	-0.564 (-2.05)**	-0.143 (-0.83)	-0.6 (-1.84)*
dummy_large	0.559 (3.08)***	0.016 (0.08)	1.279 (3.31)***	-0.944 (-2.98)***	0.00035 (0)	-0.954 (-2.6)**
dummy_very_large	0.829 (4.2)***	0.338 (1.76)*	1.459 (3.42)***	-0.872 (-2.52)**	-0.084 (-0.38)	-1.274 (-2.99)***
dummy_year	-0.326 (-1.86)*	0.219 (1.25)	0.397 (1.01)	0.394 (1.24)	0.425 (2.16)**	
lnwatercost	0.219 (2.2)**	0.12 (1.21)	0.611 (2.92)***	-0.943 (-5.56)***	-0.342 (-3.16)***	-0.356 (-1.42)
dry	-0.142 (-1.56)	0.037 (0.5)	0.001 (0)	0.057 (0.36)	-0.047 (-0.47)	0.042 (0.23)
wet	-0.052 (-0.97)	-0.009 (-0.19)	0.26 (2.06)**	-0.176 (-1.59)	-0.044 (-0.65)	-0.185 (-0.21)
Residence off farm	1.225 (2.08)**	-1.283 (-2.34)**	1.318 (1.07)	0.712 (0.67)	0.923 (1.43)	-1.424 (-1.15)
over65	1.025 (0.81)	-3.373 (-3.35)***	0.891 (0.33)	1.572 (0.71)	-1.141 (-0.81)	-1.245 (-0.47)
non white	-1.009 (-1.03)	-0.755 (-1.24)	3.884 (1.91)*	-0.238 (-0.14)	2.174 (2.04)**	-6.599 (-3.97)***
Hispanic	-1.768 (-1.31)	0.331 (0.28)	-10.032 (-3.54)***	1.475 (0.63)	4.903 (3.31)***	1.028 (0.42)
Estimation methods	OLS	regression with robust error term	OLS	OLS	OLS	OLS
observations	136	136	128	128	132	68
R-Square	0.29	0.29	0.33	0.39	0.33	0.37
White's Test	55.95	90.25**	80.46	61.05	66.77	53.93
Breusch-Pagan	10.78	7.52	15.2	12.4	12.48	12.69

T-statistics in parentheses;
significance at 1%, 5% and 10% level are denoted by ***, **, and *, respectively

Table 12 Farmers' demand for scheduling methods (continued)

	Soil-Moisture Sensing Devices	Commercial-Scheduling Services	Computer Simulation Models	Plant Moisture Sensing	Most Water-Management Intensive and Water-Conserving Means
Intercept	-4.177 (-5.78)***	-5.705 (-4.91)***	-4.17 (-2.66)***	-7.588 (-3.29)***	-3.568 (-4.95)***
dummy_medium	0.641 (2.11)**	-0.012 (-0.03)	0.997 (2.19)**	1.093 (1.34)	0.462 (1.92)*
dummy_large	0.912 (2.85)***	0.617 (1.46)	1.277 (2.36)**	1.94 (2.15)**	0.822 (3.45)***
dummy_very_ large	1.365 (3.96)***	1.068 (2.21)**	-0.128 (-0.22)	0.917 (0.88)	1.202 (4.81)***
dummy_year	-0.241 (-1.01)	0.155 (0.38)	0.275 (0.5)		-0.067 (-0.32)
lnwatercost	0.468 (3.84)***	0.567 (2.33)**	-0.568 (-1.76)*	0.396 (0.86)	0.524 (4.1)***
dry	-0.011 (-0.05)	-0.027 (-0.13)	-0.1 (-0.49)	-0.284 (-0.61)	-0.019 (-0.13)
wet	0.035 (0.4)	0.272 (1.91)*	0.329 (2.1)**	-1.519 (-0.77)	0.008 (0.11)
Residence off farm	0.642 (0.72)	-0.47 (-0.34)	0.559 (0.33)	2.099 (0.84)	1.048 (1.42)
over65	-2.875 (-1.57)	2.567 (0.83)	9.574 (3.02)***	6.441 (1.34)	-3.555 (-2.08)**
non white	5.093 (4.82)***	-1.158 (-0.54)	0.378 (0.18)	4.883 (2.06)**	-0.038 (-0.04)
Hispanic	-0.92 (-0.41)	-2.73 (-0.82)	-3.665 (-0.57)	-4.678 (-0.74)	-0.263 (-0.2)
Estimation methods	regression with robust error term	OLS	regression with robust error term	regression with robust error term	regression with robust error term
observations	132	120	119	68	136
R-Square	0.37	0.19	0.26	0.14	0.45
White's Test	99.4***	77.87	83.08	62.31	103.5***
Breusch-Pagan	29.54***	6.97	21.19**	16.89*	21.69**

T-statistics in parentheses;
significance at 1%, 5% and 10% level are denoted by ***, **, and *, respectively

Table 13 Farmers' demand for different sources of information

	Extension Agents or University Specialists	Govern-ment Specialists	Irrigation Equip-ment Dealers	Irrigation District or Water Supplier	Private Specialists or Consult-ants	Media Reports or Press	Neighbor-ing Farmers	Electronic Infor-mation Services
Intercept	-0.992 (-2.17)**	-1.013 (-2.01)**	-1.796 (-3.52)***	-0.217 (-0.33)	-6.138 (-7.86)***	-3.697 (-6.19)***	-0.268 (-0.63)	-4.438 (-4.37)***
dummy_ medium	0.401 (2.86)***	0.728 (3.69)***	0.696 (4.1)***	-0.443 (-2.47)**	1.202 (5.04)***	0.429 (2.34)**	0.075 (0.57)	0.865 (3.28)***
dummy_ large	0.467 (2.88)***	1.025 (4.72)***	0.872 (4.86)***	-0.628 (-2.59)**	1.689 (6.09)***	0.784 (3.71)***	0.213 (1.41)	0.776 (2.61)**
dummy_ very_large	0.454 (2.57)**	1.079 (4.79)***	1.275 (8.23)***	-0.782 (-3.46)***	2.174 (7.27)***	0.901 (3.91)***	0.075 (0.45)	1.363 (3.96)***
dummy_ year	0.034 (0.21)	0.234 (0.97)	-0.394 (-2.41)**	0.009 (0.05)	0.673 (2.6)**	-0.548 (-2.68)***	-0.458 (-3.14)***	
lnwatercost	0.027 (0.31)	-0.579 (-5.33)***	0.463 (4.55)***	-0.444 (-3.37)***	0.683 (4.46)***	0.343 (2.97)***	-0.092 (-1.11)	0.273 (1.35)
dry	-0.035 (-0.43)	0.057 (0.67)	-0.033 (-0.47)	-0.147 (-1.71)*	-0.106 (-0.78)	-0.053 (-0.5)	0.044 (0.59)	0.006 (0.04)
wet	0.035 (0.74)	0.068 (1.04)	-0.103 (-2.03)**	-0.045 (-0.59)	0.15 (1.84)*	0.043 (0.7)	-0.068 (-1.54)	-0.304 (-0.42)
Residence off farm	0.967 (1.84)*	0.933 (1.33)	-1.978 (-2.65)***	3.082 (4.21)***	0.82 (0.94)	-1.198 (-1.75)*	-0.001 (0)	0.44 (0.44)
over65	-1.921 (-1.71)*	1.281 (1.17)	-1.347 (-1.34)	-3.235 (-1.89)*	1.257 (0.65)	3.043 (2.07)**	0.728 (0.69)	2.789 (1.31)
non white	-0.064 (-0.07)	-0.455 (-0.37)	-1.273 (-1.47)	0.321 (0.25)	0.834 (0.58)	-0.483 (-0.42)	0.776 (0.95)	0.382 (0.28)
Hispanic	0.303 (0.25)	1.222 (0.77)	-5.684 (-4.55)***	0.887 (0.37)	-5.589 (-2.82)***	-2.65 (-1.68)*	-1.42 (-1.26)	-4.365 (-2.19)**
Estimation methods	OLS	regression with robust error term	regression with robust error term	regression with robust error term	OLS	OLS	OLS	OLS
observation	136	132	136	132	128	136	136	68
R-Square	0.27	0.42	0.63	0.24	0.58	0.26	0.19	0.35
White's Test	71.06	83.75*	97.88**	103.2***	77.38	53.97	79.42	58.79
Breusch-Pagan	6.81	21.97**	19.34*	16.69	14.02	9.22	12.16	7.48

T-statistics in parentheses;
significance at 1%, 5% and 10% level are denoted by ***, **, and *, respectively

2. Water cost

Water cost has significant coefficients in 8 out of 11 equations of scheduling methods, and in 5 out of 8 equations of sources of information.

The adoption of scheduling methods

Water cost has significant positive coefficients in the equations of 'most water-management intensive and water-conserving means', 'soil-moisture sensing devices', and 'commercial-scheduling services', but has significant negative coefficients in the equations of 'calendar schedule' and 'water delivered in turn by the irrigation organization'. This means when faced with higher water cost, farmers are more likely to adopt management-intensive methods, and less likely to adopt less management-intensive methods. The results are consistent with Hypothesis 2.

Furthermore, the marginal effect of water cost on the adoption of 'most water-management intensive and water-conserving means' is not the estimated coefficient, because the estimated equation in formula (19) is a regression of $\frac{\ln(adoption\ rate)}{1 - adoption\ rate}$. To get the predicted value of the adoption rate and the marginal effect of water cost on the adoption rate, we follow the formula (22), which is transformed from equation (19) and assumes the error term is distributed normally.

$$(22) \quad E(adoption\ rate) = \frac{1}{1 + e^{-\left(x\hat{\beta} + \hat{\sigma}^2/_2\right)}},$$

Where $\hat{\beta}$ is the vector of estimated coefficients, and $\hat{\sigma}^2$ is the estimated variance of the error.

As shown in Figure 14, water cost has a positive but decreasing marginal effect on the adoption (other variables take their mean values). For larger farms, water cost has larger marginal effects, especially when water cost is relatively low. For every 10 $/ acre feet increase in water cost, the adoption rate increases around 0.03-0.17 for very large farms, and increases around 0.02-0.05 for small farms.

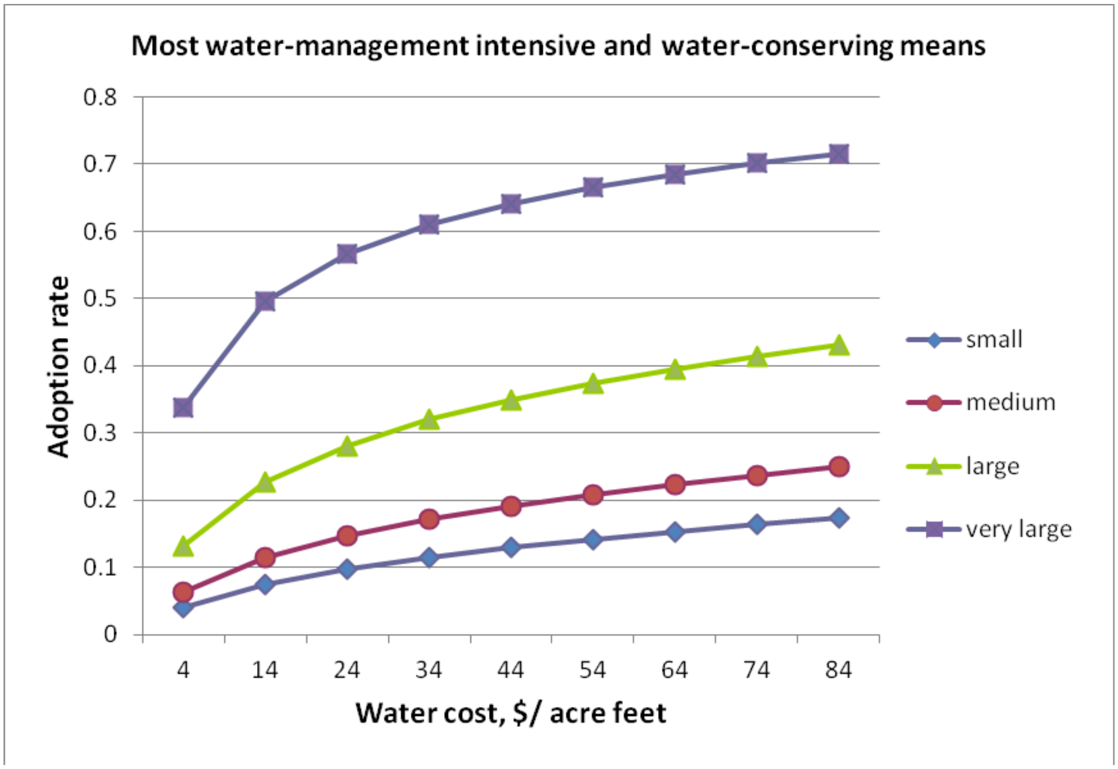

Figure 14 The effect of water cost on the adoption of "Most Water-Management Intensive and Water-Conserving Means" by farm sales size, 2008.

Intuitively, these results make sense too. When water cost goes up, farmers would be expected to reduce water applications. Therefore, they want larger portion of the applied water to be effectively used and less portion of the applied water to be lost. That is, they are pushed to improve the efficiency of the applied water. Therefore, they seek to upgrade scheduling methods, replacing less management-intensive methods with management-intensive ones.

Besides above explanation, there is another reason for the significant negative coefficient of water cost in the equation of 'water delivered in turn by the irrigation organization.' Farmers who irrigate whenever water is delivered to them by the irrigation organization also get water from the local irrigation organization. In addition, the water obtained from local irrigation organizations is surface water that usually costs less.

Exceptions to the above general results are ‘computer simulation models’, ‘condition of crop by observation’ and ‘media reports on crop water needs’. The first one is management-intensive method, but water cost has a significant negative effect on it. The two left are less management-intensive methods, but water cost has significant positive coefficients. A possible reason is all these irrigation scheduling methods work like a portfolio. Farmers pick a few methods that are less management-intensive but also cost little or even free, such as ‘condition of crop by observation’ and ‘media reports on crop water needs’.

The adoption of sources of information

Similarly, faced with high water costs, farmers are more likely to adopt specific information from private sources and less likely to use general information from public sources. Because the specific information from private sources is more customized, and thus supposed to be more efficient than the general information from public sources. As shown in the model of ‘private specialists or consultants’ and ‘irrigation equipment dealers’, water cost has a significant positive influence. In the model of ‘government specialists’ and ‘irrigation district or water supplier’, water cost has a significant negative effect.

Besides, another possible explanation for the significant positive coefficient of water cost in the equation of ‘irrigation equipment dealers’ is that farmers are more likely to invest on irrigation equipment when water cost is high. This makes sense because irrigation equipment is supposed to improve water efficiency. Therefore, they obtain information from ‘irrigation equipment dealers’.

One exception to the above general results is that water cost has a significant positive effect on the adoption of information from ‘media reports or press’.

3. Climate

The adoption of scheduling methods

As discussed in the variable section, the effects of the drought variables are expected to follow Hypothesis 2. The coefficient for variable DRY is significant only in the equation of ‘condition of crop by observation’ and is negative. This result is consistent with Hypothesis 2. However, the variable WET has significant positive coefficients in the equations of ‘commercial-scheduling services’, ‘media reports on crop water needs’, and ‘computer simulation models’. This result contradicts with Hypothesis 2. One possible reason could be that the effects of the drought on water supply and demand are complex.

The adoption of sources of information

‘Irrigation District or Water Supplier’ is the only one source of information in which the drought has a significant influence. DRY has a significant negative coefficient. This consists with Hypothesis 2.

WET has a significant negative coefficient in the equations of ‘Irrigation Equipment Dealers’, which is consistent with Hypothesis 2. However, the negative coefficient of WET in the equation of ‘Neighboring Farmers’ contradicts with Hypothesis 2. Again the possible reason is the complex relations between the drought and water supply/demand.

4. Residence off farm

The adoption of scheduling methods

The coefficients of Residence_off_farm are significant in two equations ‘Condition of Crop by Observation’ and ‘feel of soil’, with positive sign in the former and negative sign in the latter. This is consistent with Hypothesis 3, because ‘feel of soil’ requires more time than ‘Condition of Crop by Observation.’

The adoption of sources of information

Residence_off_farm has significant coefficients in four equations of sources of information. In the equations of ‘Extension Agents or University Specialists’ and ‘Irrigation District or Water Supplier’, Residence_off_farm positively influences information adoption. In the equations of ‘Irrigation Equipment Dealers’ and ‘Media Reports or Press’, Residence_off_farm negatively influences information adoption. Compared with ‘Extension Agents or University Specialists’ and ‘Irrigation District or Water Supplier’, ‘Irrigation Equipment Dealers’ and ‘Media Reports or Press’ are more time-consuming. Therefore, the results consist with Hypothesis 3.

5. Demographic characteristics

The adoption of scheduling methods

As expected, variables Over_65, Non_white and Hispanic have significant negative coefficients in four equations of scheduling methods out of 11. These scheduling methods are ‘Feel of the Soil’, ‘Neighbor Practices’, ‘Media Reports on Crop Water Needs’, and ‘Most Water-Management Intensive and Water-Conserving Means’.

The marginal effect of Over65 on the adoption of ‘Most Water-Management Intensive and Water-Conserving Means’ can be obtained from the prediction equation of the adoption rate as shown in formula (22). As shown in Figure 15, the magnitudes of the negative marginal effect of the proportion of farmers over 65 years old on the adoption rate of 'Most Water-Management Intensive and Water-Conserving Means' decrease for small and medium farms, but remain stable for large and vary large farms. The magnitudes of the marginal effects are generally larger for larger farms. For every three percentage point increase in the proportion of farmers over 65 years old, the adoption rate reduces around 0.03-0.05 for vary large farms, and reduces around 0.02-0.03 for small farms.

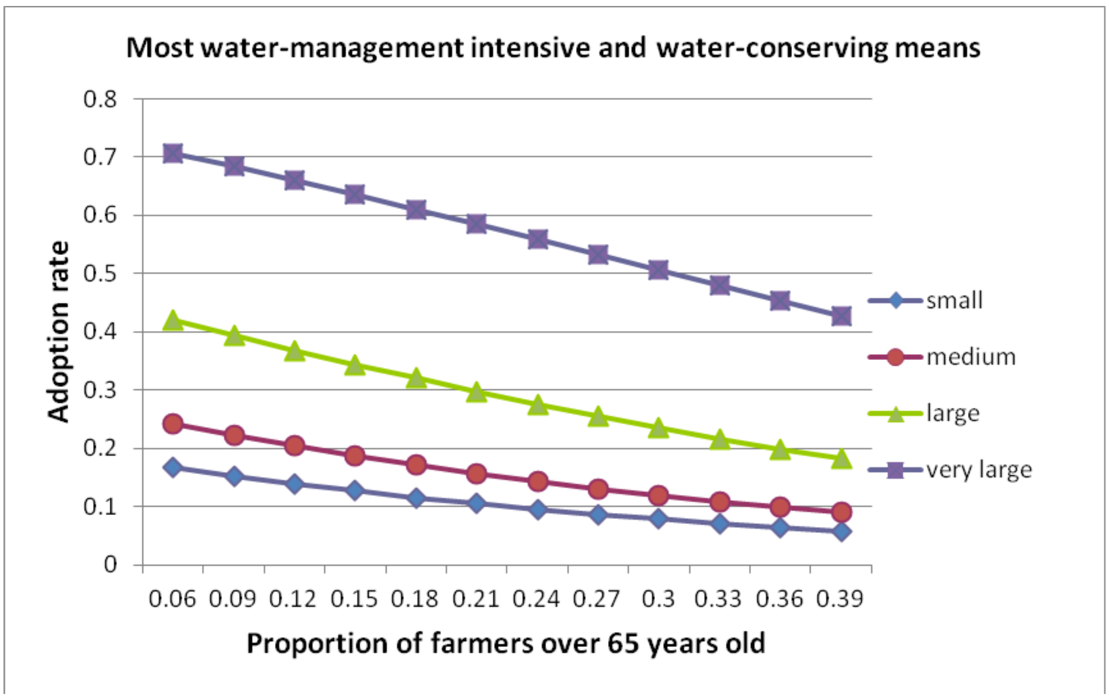

Figure 15 The effect of farmers' age structure on the adoption of "Most Water-Management Intensive and Water-Conserving Means" by farm sales size, 2008.

However, surprisingly, variables Over_65, Non_white and Hispanic have significant positive coefficients in 4 equations of scheduling methods out of 11. 'Computer Simulation Models', 'Soil-Moisture Sensing Devices', 'Media Reports on Crop Water Needs', and 'Calendar Schedule'. In the equation of 'Media Reports on Crop

Water Needs', Non_white has a significant positive coefficient, while Hispanic has a significant negative coefficient.

The adoption of sources of information

As expected, Over_65, Non_white or Hispanic have significant negative coefficients in 6 of 8 equations of scheduling methods out. Surprisingly, in the equation of 'Media Reports or Press', Over_65 has a significant positive coefficient, while Hispanic has a significant negative coefficient.

8. Conclusions

This research generalizes the model of Feder and Slade (1984) to allow for heterogeneous information, to extend the production system from information and one input to information and two inputs, and to include time cost of information and trade-offs between money and time (e.g. demand for consulting services). From this generalized framework, we get a series of hypotheses about influential factors for farmers' demand for water management information.

Although the USDA Farm and Ranch Irrigation Survey (FRIS) data for water management from ERS is in the form of the aggregate cross-tabs, it still provided interesting multivariate regression results. This suggests that continued publications of future cross-tab data provided by ERS would be worthwhile.

One finding from the data was that no one source of water management information was used by more than 50% of western farmers. While USDA and cooperative extension specialists are among the most relied upon sources of information, many farmers still do not cite them as a source of information. Generally, larger farms are more likely to adopt more irrigation scheduling methods, especially management-intensive ones. The reasons could be economics of scale and greater technical capacity associated with larger farms. Exceptions exist when the supply of some information is limited for larger farms. In 2008, large and vary large farms account for only 24% of total irrigated farms, but 79% of total applied water. This means that modern methods of scheduling are being applied for decisions affecting a large share of agricultural water use. However, there appear to be significant adoption barriers facing smaller scale farmers. Smaller farms rely more on irrigation district, so policies targeting small farms could target irrigation districts staff.

Consistent with both the hypothesis and intuition, the empirical examination shows when water cost goes up, farmers increase the adoption of some modern, management-intensive scheduling methods, and decrease the adoption of some conventional, less management-intensive methods. Similarly, faced with increased water cost, farmers adopt more information from private sources and less information from public sources. Private information may be more expensive, but more specifically tailored to particular farming operations.

On the other hand, the empirical results for some scheduling methods or use of some information sources were not significant or even contradict with the hypothesis. One possible reason is that water cost does not adequately reflect the true supply and demand, especially for surface water. Another reason could be the water cost data we use is too aggregate. Lastly, the reason could be that farmers are faced with valid budget constraints so that they cannot afford more costly water and more costly methods or information at the same time. Subsidies for management-intensive information and relevant devices could help.

The total number of water management information sources and irrigation scheduling methods increases with farm size and decreases with the proportion of farmers over 65. While measures of drought did not have a significant effect on information demand, a history of wetter than normal years discouraged information demand. Water costs do not affect the number of information sources or scheduling methods used, but do affect choice among different methods. Higher water costs encouraged greater use of more management intensive methods. The total number of information sources used was decreasing in the proportion of farmers who were Hispanic. This comes from less use of private, but not public, information sources.

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