Farmers' Adoption of Pressure Irrigation Systems and Scientific Irrigation Scheduling Practices: An Application of Multilevel Models

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Abstract

Water scarcity is becoming more acute due to climate change and it poses substantial impacts on agriculture. To conserve water and use water more efficiently for irrigation, understanding farmers' decision-making regarding irrigation technology and practice adoption is essential. Using data from the national 2013 Farm and Ranch Irrigation Survey (FRIS) conducted by USDA, this study employs a multilevel modelling approach to analyze crop-specific irrigation decisions focusing on corn and soybean farms. The results suggest that, while adoption is affected by land area, off-farm surface water, various barriers and information sources, the variability of pressure irrigation adoption is mainly accounted for by factors at the state level. However, the adoption of scientific scheduling practices is mainly accounted for by farm-level variation. Producers adopt pressure systems to respond to drought and reduce risk from extreme weather. Federal programs and policy should not only target specific barriers and increase the effectiveness of incentives at the farm level, but also address differing priorities in each state. Implications should benefit future policy design and improve education programs.

Key words: adoption, climate change, irrigation decisions, pressure irrigation systems, scientific irrigation scheduling practices

JEL Codes: Q15, Q25, Q55

1. Introduction

Climate change is expected to have substantial impacts on agriculture in the United States. For example, Ummenhofer et al. (2015) found that using multiple models, mean temperatures for the growing season in Iowa will increase by 5 °F and corn yields decrease by 18% by the end of the 21st century, thus having profound impacts on grain production and farmer livelihoods. As a result, water scarcity is becoming more acute. In the U.S., agriculture is a major water user accounting for 80% of the national consumptive use of surface and ground water; it is over 90% in many western states (Salazar et al., 2012). Regions of the U.S. that have not typically been associated with irrigation, such as the Southeast and Midwest, have seen increased adoption of irrigation in recent years to deal with potential dry conditions (Widmar, 2015). This indicates there will be more pressure to conserve water in agriculture and thus improve the sustainability of scarce water resources (Blanc and Reilly, 2015). Therefore, understanding the factors affecting adoption of enhanced irrigation technologies such as pressure irrigation systems (PIS) including drip irrigation or low-flow sprinklers, and of scientific irrigation scheduling practices (SIS) such as soil and plant moisture sensing devices, and commercial scheduling services, is needed to overcome real or perceived barriers to increasing adoption and conserving water through policy intervention or educational efforts.

While studies have focused on different combinations of factors to analyze the adoption of farm best management practices, the effects of various barriers, information and climate change have been understudied, in particular, their effects at the farm level. In addition, the relationship between advanced irrigation methods and scientific scheduling practices needs to be examined. To better understand U.S. farmers' adaptation behaviors to climate change and the barriers, we study the adoption of enhanced farm irrigation technologies and of scientific scheduling practices using an available USDA farm-level dataset. Specifically, this study aims to answer the following fundamental questions:

1) What are the major barriers to adoption of enhanced farm irrigation technologies, and what information is needed to overcome those barriers?
2) Are there any differences in adoption determinants between embodied technologies (e.g., pressure irrigation) and technologies that primarily provide improved information for irrigation practices (e.g., soil moisture sensors)?
3) How do farmers' perceptions of climate risks and climate variability affect their adoption behaviors and irrigation decisions?

2. Literature review on farmers' water conservation practices

Water conservation in the agriculture sector is fundamental to the sustainable use of scarce water resources (Ayars, Fulton, and Taylor, 2015; Bozzola and Swanson, 2014). Traditionally, farms have been irrigated using gravity irrigation systems (also known as surface or flood irrigation), where water carried by canals or pumped from wells flows to fields by the force of gravity. The water soaks slowly into the field to irrigate crops. In some cases small trenches or furrows are created in the field to guide water flow. This method is generally less efficient than newer technologies and its use has been decreasing in the U.S. according to the Census of Agriculture (NASS, 2014).

Various approaches to water conservation have been explored, such as developing new irrigation techniques (e.g., Tanwar et al. (2014)), improving water use efficiency, increasing investment in irrigation infrastructure such as canals, wells and drip systems (e.g., Kang et al. (2012)), and designing water conservation policies (e.g., Bozzola and Swanson (2014)). Water-conserving irrigation systems have been proposed and applied to various crops in many farming areas around the world. For instance, in eastern Australia (Sadras and Rodriguez, 2010), arid and semi-arid areas in China (e.g., Fan, Wang, and Nan (2014) and Kang et al. (2012)), and southern and southeastern U.S. (Salazar et al., 2012; Schneider and

Howell, 2001; Vories et al., 2009). Examples include pressure (or pressurized) irrigation systems (versus gravity irrigation methods), including linear move, center pivot, sprinkler and drip irrigation methods. Field experiments with sprinkler and drip irrigation and their comparison with traditional flood or furrow irrigation have been conducted on various crops worldwide (e.g., Dağdelen et al. (2009), Ibragimov et al. (2007), Liu et al. (2010), Salvador et al. (2011), and Usman et al. (2010)). As a result, crop irrigation water use efficiency (the amount of crop output per unit of water applied) can be improved and a substantial quantity of water could be conserved by enhanced irrigation systems[1].

In addition, scientific irrigation scheduling has been adopted to determine when and how much to irrigate. Some common practices adopted by U.S. farmers include the condition of crops, reports on crop evapotranspiration, soil moisture sensors, irrigation scheduling models (George, Raghuwanshi, and Singh, 2004; George, Shende, and Raghuwanshi, 2000; Leib, Elliott, and Matthews, 2001; Sammis et al., 2012), irrigation scheduling services (Pereira, 1999), etc. Focusing on the application of irrigation scheduling tools in cotton production with under-surface irrigation in central Arizona, Hunsaker et al. (2015) compared ET-based irrigation scheduling methods with traditional border-irrigation scheduling practices. Their results showed that compared with experience-based irrigation decision-making, the ET-based irrigation scheduling could improve irrigation water productivity, and indicated that there was great potential for conserving water on surface-irrigated cotton fields.

Much research has shown enhanced irrigation systems and scientific scheduling practices could improve irrigation water use efficiency, conserve water and/or increase grain yield. In

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[1] According to the Jevons Paradox, increased efficiency tends to increase overall resource use. As water use efficiency increases, farmers might irrigate more acres. Given the limited availability of water and the fact that the overall irrigated area in U.S. was roughly flat in 1997-2012 (though we see variation of irrigated area in states like Mississippi, Illinois, Iowa, Kansas, etc.), the Jevons Paradox is less likely to be an issue for water resources across the U.S. Thus, this paper will not focus on the paradox.

studying the application of improved practices for farm irrigation in Alberta, Canada, Bjornlund, Nicol, and Klein (2009) concentrated on improved irrigation technologies including advanced pressurized methods, and improved management practices including monitoring soil moisture using hand-feel method, soil monitoring instruments, computer programs and private consultants. There was a potential of a 30% increase in water use efficiency which implies a need for increasing the adoption of more efficient practices for farm management, and improving efficiencies of irrigation systems in the short term. Based on a database management system, George et al. (2000) built an irrigation model for the adoption of scheduling farm irrigation with multiple choices for improving both single and multiple field management. With the flexible and user-friendly tool for scheduling farm irrigation, water was used more efficiently on bean farms, and their yield is increased.

Technologies can also be complementary and adopted as a package. Weber and McCann (2015) found that conservation tillage increased the adoption of nitrogen inhibitors and plant tissue testing, while irrigation decreased the adoption of nitrogen soil testing. Kara, Ribaudo, and Johansson (2008) confirmed that conservation practices are likely to be co-adopted with others, including conservation tillage, yield monitors, grassed waterways, commercial fertilizer plan, manure management plan, erosion plan, soil nutrient testing, and filter strips. Similarly, efficient use of irrigation water through enhanced irrigation methods can also be facilitated by other information provided by commercial companies, government, environmental organizations, etc.

3. Hypotheses

In this section, factors affecting farmers' adoption behaviors and irrigation decisions are reviewed, and hypotheses are constructed. Farmers' adoption of irrigation practices is hypothesized to be a function of expected profit, costs, perceived barriers, information availability, farm and farmer characteristics, and their environmental attitudes and perceptions of climate change.

Profitability, or lack thereof, is a leading determinant affecting adoption of farm conservation practices (Contant and Korsching, 1997; Gedikoglu and McCann, 2012; Gedikoglu, McCann, and Artz, 2011; Núñez and McCann, 2005; Prokopy et al., 2008). Lambert et al. (2006) pointed out that due to high expected profits of the management intensive BMPs, their adoption rates were also high among commercial farmers. High expected profits were reported to be major factors for Iowa swine farmers when adopting manure management techniques (Fleming, Babcock, and Wang, 1998). Therefore, farmers are hypothesized to adopt the practices if they expect higher profits.

Cost can be fundamental for farmers' decision-making in adopting new irrigation technologies. According to various reports, the capital and annual costs for surface irrigation range from $67 (Colorado Agricultural Water Alliance, 2008) to $200 per acre (Amosson et al., 2011). For sprinkler systems, total annual costs for capital, operating and ownership can range from $468 (Amosson et al., 2011) to $1273 per acre (Scherer, 2010). For drip irrigation systems, the annual costs for installation and operation is $1009 (Amosson et al., 2011) to $1200 per acre (Simonne et al., 2008). In addition, costs of moisture sensing devices include installation, manual measurement, data logging, data transmitting, and data interpretation. The annual costs differ based on technology and source, ranging from $500-$900 to measure one field with a specific soil type at three depths (Payero et al., 2013) to around $1300-$2000 or more to measure several fields (Morris and Energy, 2006). Per acre costs will depend on the size of the field. Low costs also increased the adoption of manure management techniques in Iowa swine farmers (Fleming et al., 1998). Adoption of these technologies and sensing devices thus requires financial investments (Bogena et al., 2007) and high costs are expected to decrease adoption.

Adoption of these irrigation practices faces many barriers. Using data on 17 western states from the USDA Farm and Ranch Irrigation Survey (FRIS), Schaible, Kim, and Aillery (2010) studied dynamic adjustment of irrigation technology and pointed out some major barriers impacting the adoption of enhanced irrigation technologies. The most important barriers were related to investment cost and financing issues. Greater sharing of costs by government or landlords for installation of advanced irrigation techniques can improve their adoption rates especially for beginning farmers with limited resources and social disadvantages (Schaible and Aillery, 2012). Moreover, uncertainty about future water availability and farming status could influence farmers' willingness to adopt. Hence, uncertainties regarding potential costs and future benefits will limit adoption of water conservation practices (Rogers, 2003; Sunding and Zilberman, 2001).

Information availability and its sources can affect farm irrigation decisions (Prokopy et al., 2008). On the one hand, limited information can be an obstacle to adopting irrigation technologies. Rodriguez et al. (2009) pointed out that lack of information on irrigation, crop management, effectiveness of practices and government programs could be common obstacles for early adopters when facing the uncertainty of changing to something unknown. On the other hand, effective information can facilitate optimal irrigation decisions by farmers. Frisvold and Deva (2012) studied water information used by irrigators and the relationship of information acquisition and irrigation management. Their study indicated that appropriate information use could benefit irrigation management and crop production for farmers with varying acreage. Thus more information on how to conserve water is expected to increase adoption of water-saving irrigation practices (Nowak, 1987; Pannell et al., 2006; Rogers, 2003).

In addition, adoption can also be affected by farm characteristics including soil conditions, topography, farming system, size, etc. Schaible et al. (2010) found that some physical conditions of crop and field as well as topography affected irrigation adoption. Kadiyala et al. (2015) reported that soil properties and soil moisture were important indicators for adoption of irrigation management practices. Farm size (measured by sales or acres) is positively associated with the adoption of technologies (Feder, Just, and Zilberman, 1985; Kara et al., 2008) and farm BMPs (Daberkow and McBride, 1998; Lambert et al., 2006; Prokopy et al., 2008). Larger farm size was positively associated with adoption of conservation tillage (Fuglie and Kascak, 2001), integrated pest management practices, soil testing, and precision soil sampling (Walton et al., 2008). Bekele and Drake (2003), and Jara-Rojas, Bravo-Ureta, and Díaz (2012) showed that larger farm size significantly increases the adoption of recommended irrigation practices and of drip irrigation systems. Considering the large up-front cost involved with new irrigation technologies mentioned above, which implies economies of scale, farm size is hypothesized to have a positive effect.

Furthermore, water sources can be good indicators of water supply institutions. Olen, Wu, and Langpap (2016) found among West Coast farms, the adoption of sprinkler and drip irrigation were negatively associated with water from federal and surface supply, while positively associated with ground water supply. Thus, more wells are expected to increase the adoption of irrigation practices, while surface water decreases their adoption. In addition, surface water in the West is a “use it or lose it” system (Dellapenna, 2010), so producers have little incentive to conserve.

Regional variables could capture differences in climate, water institutions, and supporting infrastructure (Negri, Gollehon, and Aillery, 2005) as well as farming systems. More generally, which irrigation technologies are appropriate will vary spatially. For example, western states tend to have concentrated irrigation acreage and their irrigation institutions are well established (Negri et al., 2005). Eastern and southern states receive moderate amounts of rainfall to support agriculture and do not rely as heavily on irrigation.

Thus, we hypothesize that compared with those in the high plains states, more farmers in western states will adopt irrigation practices, while fewer farmers in midwestern and southern states adopt.

Individuals should not only have adequate knowledge about the consequences of their activities on the environment but also be able and motivated to respond. Regarding irrigation technology and BMP adoption, awareness of climate change (e.g., drought and heat waves) could motivate farmers to prepare for and take actions to adapt to future risks to production (Jin et al., 2015; Li, Ting, and Rasaily, 2010). Olen et al. (2016) found farmers were more likely to adopt advanced water-saving irrigation systems, for instance, sprinkler, to mitigate and adapt to various weather and climate impacts including frost, heat, drought, etc. Therefore, farmers are hypothesized to adopt if they perceive less precipitation, higher temperature or more losses due to droughts in the future. This is proxied by weather in 2011 and 2012.

4. Data

A national dataset from the USDA 2013 Farm and Ranch Irrigation Survey (FRIS) was used in this study. The survey was designed by the USDA Water Initiative Team, collaborating with the National Agricultural Statistics Service (NASS) and the Economic Research Service (ERS), as well as personnel from government organizations and universities with expertise in agricultural irrigation and the irrigation industry (NASS, 2014). The survey was conducted primarily by mail in January-May of 2014 after pretesting and modification, and the mailings were initially sent out to approximately 31,300 farm and ranch operations covering the major irrigators in each state. Data were also collected by Electronic Data Reporting via the internet, telephone, and personal enumeration with the input of NASS field office staff. The final response rate was 77.8 percent with data available on 34,966 farms in the 50 states, and thus FRIS represents a very high quality dataset.

At the farm level, farmers' irrigation decisions and water conservation practices are studied. As presented in the descriptive statistics below, this study incorporates independent variables on water cost, expenditures on irrigation equipment, labor payment, area of land owned or leased, water sources, barriers to improvements, information sources, production regions, etc. Variables related to water sources, federal assistance, barriers and information sources are dummy variables, and all other independent variables are continuous.

At the state level, the explanatory variables are state-level average changes in precipitation and temperature in 2011 and 2012 compared with the averages for 1981-2010 (National Oceanic and Atmospheric Administration (NOAA)). The application of a two-level model focuses on corn and soybean farms regarding the adoption of PIS and SIS compared to traditional practices[2]. In this study, pressure (or pressurized) irrigation systems include linear move, center pivot, spray, sprinklers, drip irrigation, etc. Adoption of scientific scheduling practices refers to application of at least one of the following: soil/plant moisture-sensing devices, commercial and government irrigation scheduling services, or reports on daily crop-water evapotranspiration use from internet, TV, etc.

There are more than 30 variables included in each equation. Though the FRIS dataset is regarded as a high-quality, highly representative sample, more than half of these variables have missing values. By excluding and/or appropriately transforming variables with missing values, this study includes 4761 corn farms and 3491 soybean farms in Plains, midwestern and southern states[3].

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[2] Traditional irrigation typically uses gravity systems, including flood, furrow, and border irrigation. Traditional irrigation scheduling practices include condition of crop based on farmers' observation or experience, and feel of soil. In the later analysis, the benchmark for the adoption of pressure irrigation systems is gravity systems, while the benchmark for the adoption of scientific scheduling practices is traditional scheduling practices only.

[3] Though there are multiple techniques to deal with the missing values, e.g., imputation, this study is not focusing on any. Appropriate treatment of the missing values may determine the quality of the analysis,

5. Methods

Farmers are assumed to make irrigation and adoption decisions to maximize expected utility, which is affected by a set of influential factors. Given the complexity of the FRIS data mentioned above, a multilevel model could deal with factors at multiple hierarchical levels affecting the variation of responses (Lu and Yang, 2012). The model includes both farm- and state-level equations. The farm-level equation specifies effects of the influential factors on farmers' decisions regarding adoption of PIS and SIS (eq. 1). The state-level equation enables us to access whether some state-level factors account for the variability in adoption behaviors. For the two-level model, this paper examines corn and soybean farms as an example[4] and a general model specification is constructed as indicated below.

For the research questions, suppose an individual farm i grows one specific crop ($i = 1, \ldots, N_j, and \ \sum_1^J N_j = N$) in the j^{th} state in U.S. ($j = 1, \ldots, J$). Specifically, at the farm level, dependent variables are famers' decisions regarding adoption of irrigation methods and scientific scheduling practices, and a series of independent variables ($\boldsymbol{X_{ij}}$) represent all the influential factors mentioned above. At the state level, we have a set of variables ($\boldsymbol{Z_j}$) measuring climate variability. The model estimation takes two steps. In the first step, a single regression equation can be specified in each state to estimate the effects of the explanatory variables (Ene et al., 2015). The estimation can be specified as:

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biasedness and validity of the results. For this survey, respondents were asked to mark all that apply for questions regarding scheduling practices, barriers to improvements, information sources, thus we treated missing values a zero (and those marked had been coded as one in the data). While for questions to answer "yes" or "no" or specific numbers, for example, acres, irrigation systems, water sources and amount, etc. their missing values were treated as real missing and the corresponding observations were excluded from the analyses. In addition, these three regions have 79% of corn farms and 89% of soybean farms in the lower 48 states.

[4] Corn and soybeans are the most commonly planted crop and accounts for 30% and 20% of total number of irrigated farmers in the survey. Results on other crops turn out to be very similar.

$$\boldsymbol{Y_{ij}} = \beta_{0j} + \boldsymbol{\beta_{1j} X_{ij}} \tag{1}$$

where $\boldsymbol{Y_{ij}}$ can be one of the crop-specific dependent variables in i^{th} individual farm ($i = 1, \dots, N_j$) in the j^{th} state ($j = 1, \dots, J$).

In the second step, the intercepts, $\boldsymbol{\beta_{0j}}$'s, are considered as parameters varying across states as a function of an overall mean (γ_{00}) and a random error term (u_{0j}). The β_{1j}'s are assumed fixed across each state and are presented as a function of constant parameters (γ_{10}).

$$\boldsymbol{\beta_{0j}} = \gamma_{00} + \boldsymbol{\gamma_{01} Z_j} + u_{0j} \tag{2a}$$

and

$$\boldsymbol{\beta_{1j}} = \boldsymbol{\gamma_{10}} \tag{2b}$$

The γ_{01} is a slope coefficient, representing the effects of the state-level variables (Z_j) on the β_{0j}'s, and γ_{10} represents the constant parameter, β_{1j}.

Combining eq. 1, 2a and 2b, we have:

$$\boldsymbol{Y_{ij}} = \gamma_{00} + \boldsymbol{\gamma_{10} X_{ij}} + \boldsymbol{\gamma_{01} Z_j} + u_{0j} \tag{3}$$

The model is called a random-intercept only model, as "the key feature of such models is that only the intercept parameter in the Level-1 model, β_{0j}, is assumed to vary at Level-2" (Raudenbush and Bryk, 1992: p.86) as cited by Guerin, Crete, and Mercier (2001).

For the crop-specific adoption decisions, the multi-level models are utilized to analyze the adoption of PIS and SIS for corn and soybean farms. Given the adoption decisions are dichotomous, three sequential models are estimated for each decision (Ene et al., 2015), that is, a two-level model with random effects for the intercept only without any predictors (model 1), random effects for the intercept and only level-1 fixed effects (model 2), and random effects for the intercept and both level-1 and level-2 fixed effects (model 3). To determine how much of the variability in the responses is accounted for by the factors at the state level, the intraclass correlation coefficient (ICC) is usually computed from the null model (model 1) (Ene et al., 2015) following:

$$ICC = \frac{\tau_{00}}{\tau_{00}+3.29} \tag{4}$$

where τ_{00} is the covariance parameter estimate for the intercept. The level-1 error variance is estimated to be 3.29 (Snijders and Bosker, 1999).

This multilevel model has been applied in social science research (Dolisca et al. (2009) and Guerin et al. (2001)). With official permission, the FRIS dataset was analyzed using software SAS 9.4 at the USDA-NASS National Operations Division offices in St. Louis, Missouri.

6. Results

6.1. Descriptive statistics

The summary statistics of the independent variables are presented in table 1. Farmers may use water for irrigation from one or more sources. Four water sources are investigated including groundwater only, on- and off- farm surface water only, and two or more water sources (Yes=1, No=0). For both corn and soybean farms, about 80% use groundwater only, while water from on- or off-farm surface sources only account for about 4% of farms. About 13% of farms get water from two or more sources.

[Insert table 1 about here]

Water costs are measured by the payment for off-farm surface water and energy expenses for pumping groundwater. The expenditures on facility and infrastructure and labor payment are also calculated as the farm mean values. The average cost for off-farm surface water is 3.09 and 4.31 dollars/acre-foot for corn and soybean farms, respectively. The average energy expenses are 49.20 and 35.86 dollars/acre for corn and soybean farms. The average facility expenses and labor payments are 38.20 and 1.32 dollars/acre for corn, and 24.07 and 1.45 dollars/acre for soybeans.

Regarding the farm characteristics, the average number of wells used to irrigate corn and soybeans are 6.43 and 7.54, respectively. For irrigation systems, about 22% use gravity systems only, while those only using sprinkler or drip irrigation account for 45% and 12%, respectively. The variables on farming area include the total farming area and the percentage of land owned by the farmer. The mean areas of total land are 1,839 and 1,666 acres/farm for corn and soybeans, and the percentage of owned land is 48% and 45%. About 20% of the corn farmers received federal assistance to improve irrigation and/or drainage systems, compared to 22% for soybean farms.

Regarding the barriers to implementing improvements for the reduction of energy costs or water use, nine barriers are investigated in the national survey. Respondents can select one or more barriers they are facing. Major ones include: investigating improvement is not a priority at this time (16% for corn farmers and 14% for soybean farmers), limitation of physical field or crop conditions (10% for both corn and soybean farmers), not enough to recover implementation costs (17% for corn farmers and 20% for soybean farmers), cannot finance improvements (12% for both corn and soybean farmers), and landlords will not share improvement costs (12% for corn farmers and 14% for soybean farmers).

For the eight sources of irrigation information, the top ones are extension agents (35% for corn farmers and 40% for soybean farmers), private irrigation specialists (38% for corn farmers and 37% for soybean farmers), irrigation equipment dealers (32% for corn farmers and 30% for soybean farmers), neighboring farmers (23% for both corn and soybean farmers), e-information services (19% for both), and government specialists (15% for both).

Regarding location, this study includes more farms in the Plains states, 67% for corn and 56% for soybeans, and fewer farms in the Midwest and South, accounting for 19% and 14% for corn, and 23% and 19% for soybeans.

The state-wide average weather related variables are presented in table 2 for the 21 states planting both corn and soybeans. Compared with the 1981-2010 average precipitation, the changes for 2011 and 2012 are -1.61 and -5.27 inches. Compared with the 1981-2010 average temperature, the changes for 2011 and 2012 are 0.75 and 2.92 ℉. While in 2013, the year covered by the survey, the precipitation is 3.52 inches more than the average and temperature is 0.90 ℉ lower than the average (not shown in the table). This indicates the rainfall is more favorable for agricultural production in 2013.

The summary statistics of dependent variables[5] are also presented in table 2. Among the 4761 irrigated farms planting corn in 2013, about 84% had adopted pressure irrigation systems, and 39% had adopted at least one of the four scientific irrigation scheduling practices. There are 3491 soybean farms with 70% adopting pressure irrigation, and 36% adopting scientific scheduling practices.

[Insert table 2 about here]

6.2. Estimation results

The results of ICC for the multilevel models are presented in table 3. Regarding corn farms, the ICC values are 0.743 and 0.073 for the adoption of pressure irrigation systems and scientific irrigation scheduling practices, respectively, while for soybean farms, the values are 0.838 and 0.114. As an example of interpreting this measure, 0.743 means 74.3% of the variability in the PIS adoption on corn farms is accounted for by the variation between states. We find a very high proportion of the variability in adoption of pressure systems for both corn and soybeans are accounted for by the state-level differences, while a very low proportion of the variability in adoption of scientific scheduling practices is accounted for by the states.

[Insert table 3 about here]

Tables 4-7 present the multilevel model results of the crop-specific adoption decisions as

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[5] The crop-specific analyses just focus on farms that are at least partially irrigated, while excluding non-irrigated farms.

well as the fit statistics. In the four tables, Akaike information criterion (AIC) indicates a better fit for the last model. So, the following interpretation will focus on model 3 in each table as they also incorporate the state-wide variables. A comparison of the same type of adoption on two different crops can provide a better understanding of farming systems.

6.2.1. Pressure irrigation systems

Results for the adoption of pressure irrigation systems are presented in table 4 for corn and in table 5 for soybeans. The reference category is gravity irrigation for both crops.

[Insert table 4 and table 5 about here]

Water sources. Compared to farm irrigation using groundwater only, corn farmers using off-farm surface water only are less likely to adopt PIS. For soybean farmers, using water from on- and off-farm surface and multiple sources decreases the adoption of PIS compared to those using groundwater only. These results indicate use of groundwater tends to increase the PIS adoption for both crops.

Costs. The results show a higher cost for off-farm surface water has a negative effect on PIS adoption on soybean farms. Higher energy expenses are associated with PIS adoption on corn farms, while higher facility expenses are associated with PIS adoption on both corn and soybean farms. Higher labor payment is associated with decreased PIS adoption for both corn and soybean farmers.

Farm characteristics. More wells are negatively associated with adoption of pressure systems. This is consistent with the hypothesis as mentioned above that more wells provide farmers more and easier access to water. Total farming area has a positive effect on corn and soybean farmers' adoption, and the percentage of owned land show a positive effect on PIS adoption for corn. These findings indicate that more land is associated with adoption of more efficient irrigation systems, which saves water and thus decreases water application for irrigated farms. In addition, federal assistance increases the PIS adoption on soybean farms.

Barriers to improvements. Barriers to improvements show varying effects on the adoption of PIS. The barriers decreasing PIS adoption include: not enough to recover implementation costs, landlords will not share improvements costs, will not be farming long enough, uncertainty about future water availability (for soybeans), and will increase management time or cost (for corn). This is consistent with the hypotheses as the adoption requires high initial investments. The positive effects are interesting and need further investigation.

Information sources. For the adoption of pressure systems, information from neighboring farmers has a negative effect on both corn and soybean farms, while information from extension agents, private irrigation specialists, irrigation equipment dealers, local irrigation district employees, and media reports has positive effects on both crops, and E-information services only have a positive effect on corn. These are in line with the hypotheses as information on irrigation and water conservation can encourage farmers to use water more efficiently.

State-level variables. The multi-level model incorporates fixed effects of state-wide average weather conditions and region dummies. Enhanced irrigation systems can be introduced before the growing season and afterward used when needed. The change of precipitation in 2011 and 2012 is negatively associated with the application of pressure systems on both corn and soybean farms in 2013, indicating more water availability decreases producers' initiative to save water and to irrigate farms more efficiently, or they even don't need to irrigate that much. Similarly, the PIS adoption by both corn and soybean farmers is positively influenced by the temperature changes in 2012, indicating a major effect of perceptions of climate variability on the adoption of advanced irrigation systems. Compared to the Plains states, corn farmers in the South are less likely to adopt PIS, in line with expectations.

6.2.2. Scientific irrigation scheduling practices

The estimation results of the SIS adoption are presented in table 6 for corn farmers and in table 7 for soybean farmers.

[Insert table 6 and table 7 about here]

Water sources. Compared with using groundwater only, on-farm surface water use decreases the SIS adoption on both corn and soybean farms. Using water from off-farm surface or multiple sources increases the adoption for both crops.

Costs. The results show higher off-farm surface water cost increases the SIS adoption on corn farms, while it decreases the adoption on soybean farms. Higher energy expenses is associated with more SIS adoption on soybean farms, and both facility expenses and labor payment have positive effects on the SIS adoption for both crops.

Farmer characteristics. Contrary to the adoption of PIS, more wells increase SIS adoption. Larger farming area has a positive effect on SIS adoption on both corn and soybean farms. For both corn and soybean producers, those who received technical and financial assistance on irrigation and drainage improvements are more likely to adopt SIS.

Barriers to improvements. Varying effects of the barriers are found on SIS adoption. The variables decreasing adoption include investigating improvements is not a priority, cannot finance improvements, will not be farming long enough, and will increase management time or cost. This is in alignment with the hypotheses on barriers. Similar to the PIS adoption, risk of reduced yield or poorer quality crop, physical limitation and high costs not recovered or shared has a positive effect. This perhaps is true as farmers may be able to access some public, government reports to get some idea of soil moisture conditions even lacking other financial support. However, more information should be obtained to better understand these effects.

Information sources. Regarding the SIS adoption on both corn and soybean farms, positive effects are found with information from extension agents, private irrigation specialists, irrigation equipment dealers, government specialists, media reports, and e-information services. However, information from neighboring farmers shows a negative effect, which is similar to the PIS adoption.

State-level variables. As mentioned above, the ICC in the null model of both crops shows a low percentage of the SIS adoption is accounted for by factors at the state level. Thus, the SIS adoption is less responsive to climate variability. The precipitation change in 2011 and 2012 has a negative effect on the adoption by corn farmers. The temperature changes in 2011 and 2012 have a positive effect on the adoption by corn farmers, and the 2011 temperature changes have a positive effect on the adoption of soybean farmers. These results are consistent with the expectations. Compared to the Plains states, farms in the South are less likely to adopt SIS. It seems these lower cost practices could more easily be implemented compared with PIS, while other factors at the farm-level like information should be more considered.

7. Discussion and conclusions

Using 2013 FRIS data, this study analyzes US farmers' adoption decisions of irrigation practices using a multilevel modeling approach. Given the heterogeneity of farms across the country (Olen et al., 2016) and complexity of large survey data (Lu and Yang, 2012), the analyses just focus on two crop-specific equations using a two-level model with corn and soybeans as examples. The two-level model structure incorporates both farm- and state-level determinants for corn and soybean farms. The analysis could help improve the design of educational programs and policies, and provide input to those who develop new technologies and techniques.

Perceived barriers to improvements show diverse effects on irrigation decisions and farmers' adoption behaviors on corn and soybeans. The technical and financial assistance from government is significant in increasing the adoption of PIS and SIS. Due to various important impediments, the effectiveness of support programs can be weakened and some even fail to achieve their intended goals due to the lack of funding, potential uncertainties, and physical limitations (Rodriguez et al., 2009). This finding has important policy implications because federal assistance is commonly deemed as a means to conserve water by encouraging adoption of water saving irrigation technologies. The goals by government to conserve water use, and by farmers to increase short term profits, should be aligned in the design of policies regarding agricultural technology adoption (Wang, Park, and Jin, 2015). Though improved irrigation technologies and scheduling practices can improve crop yield or quality, and reduce energy costs, labor costs, and water use (George et al., 2000; Ward, Michelsen, and DeMouche, 2007), given the needs of heterogeneous farmers, federal programs and policy should target specific barriers and increase the effectiveness of the incentives. For instance, an irrigation technology subsidy is more effective in a preventive stage to save water (Wang et al., 2015), and adoption decisions should be made before the growing season.

Information from various providers matters. Most of the adoption decisions are adviser-driven rather than farmer-driven (Stevens, 2007), thus increasing farmers' dependence on information providers. Inadequate information clarifying the costs/benefits of adopting, the technical difficulties in implementing, and the likely environmental impacts of new practices can also be other barriers to conserving irrigation water through increasing technology adoption (Rodriguez et al., 2009).

Both PIS and SIS adoption is affected by climate variability. The findings provide valuable information about how farmers might respond to perceptions of climate variability and adapt to climate risks in agricultural production. Producers can adopt pressure irrigation systems to respond to drought that may lead to high crop losses, thus reducing risks from extreme weather. Using water more efficiently, farmers can improve their resilience and coping capacity to deal with climate risks and mitigate the adverse effects. High values of ICC for adoption of pressure irrigation suggest the variation at the state level accounts for a larger proportion than the variation at the farm level. This finding indicates that federal policy design should not only recognize the heterogeneity of farms, but also address differing priorities including adaptation to various climate risks in each state.

This study calls for further investigation on crop-specific irrigation decisions and the interaction effect of water shortage and climate change. Adoption of pressure irrigation systems and scheduling practices can be estimated simultaneously if more detailed farm-level data on climate change are available, as well as their joint effects on the irrigation rate of specific crops. Ideally a farm-level survey can be conducted to generate data investigating various aspects of climate change perceptions by farmers growing specific crops (Arbuckle, Morton, and Hobbs, 2015) and their association with adoption of various irrigation practices. Also, the joint decision-making to conserve water can be analyzed considering irrigation of multiple crops. Further research could address these limitations.

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Table 1. Summary statistics of farm-level independent variables and region dummies.

	Corn (N=4761)		**Soybeans (N=3491)**	
	Mean	***Std Dev***	***Mean***	***Std Dev***
Water sources				
Groundwater only (base)	0.80	1.02	0.81	0.95
On-farm surface water only	0.04	0.51	0.04	0.47
Off-farm surface water only	0.04	0.47	0.03	0.41
Two or more water sources	0.13	0.84	0.12	0.79
Costs				
Cost for off-farm surface water($/acre-foot)	3.09	40.87	4.31	49.60
Energy expenses ($/acre)	49.20	199.68	35.86	63.54
Facility expenses ($/acre)	38.20	398.10	24.07	304.35
Labor payment ($/acre)	1.32	25.14	1.45	26.63
Farm characteristics				
# of wells used	6.43	25.43	7.54	24.81
Total acre	1839	6787	1665	5414
% of owned land	0.48	0.95	0.45	0.88
Federal assistance	0.20	1.02	0.22	1.01
Barriers to improvements				
Investigating improvement is not a priority	0.16	0.93	0.14	0.84
Risk of reduced yield or poorer quality crop	0.09	0.72	0.07	0.62
Limitation of physical field or crop conditions	0.10	0.77	0.10	0.74
Not enough to recover implementation costs	0.17	0.95	0.20	0.97
Cannot finance improvements	0.12	0.82	0.12	0.78
Landlords will not share improvement costs	0.12	0.81	0.14	0.84
Uncertainty about future water availability	0.11	0.78	0.08	0.66
Will not be farming long enough	0.07	0.64	0.06	0.57
Will increase management time or cost	0.08	0.69	0.06	0.60
Information sources				
Extension agents	0.35	1.21	0.40	1.20
Private irrigation specialists	0.38	1.24	0.37	1.18
Irrigation equipment dealers	0.32	1.19	0.30	1.12
Local irrigation district employee	0.08	0.67	0.06	0.58
Government specialists	0.15	0.91	0.15	0.86
Media reports	0.12	0.82	0.12	0.79
Neighboring farmers	0.23	1.06	0.23	1.03
E-information services	0.19	1.00	0.19	0.95
Regions				
Plains (base)	0.67	1.20	0.56	1.21
Midwest	0.19	1.01	0.19	0.96
South	0.14	0.87	0.25	1.06

All variables have been weighted using weights provided within the FRIS data.

Table 2. Summary statistics of state-level weather-related independent variables and crop-specific dependent variables.

Variable	Description (Unit)	N	Mean	Std Dev	CV	Min	Max
***State-wide average weather-related* variables**							
PrecipChange2011	Precipitation in 2011 — Average precipitation in 1981-2010 (inch)	21	-1.61	8.15	5.07	-15.87	16.50
PrecipChange2012	Precipitation in 2012 — Average precipitation in 1981-2010 (inch)	21	-5.27	4.77	0.91	-12.21	4.00
TempChange2011	Temperature in 2011 — Average temperature in 1981-2010 (F)	21	0.75	0.67	0.89	-0.80	2.10
TempChange2012	Temperature in 2012 — Average temperature in 1981-2010 (F)	21	2.92	0.85	0.29	1.10	4.00
Crop-specific dependent variables							
Corn							
PressureIrrigation	Adoption of pressure irrigation systems: hand-move, solid set, side roll, big gun, linear move, center pivot, low flow systems, etc., Yes=1; No=0	4761	0.84	0.94	1.13	0	1
SchedulingPractice	Adoption of scientific scheduling practices: at least one of soil/plant moisture-sensing devices, commercial/government scheduling services, and reports on daily crop-water evapotranspiration use, Yes=1; No=0	4761	0.39	1.24	3.21	0	1
Soybeans							
PressureIrrigation	Same as above	3491	0.70	1.12	1.62	0	1
SchedulingPractice		3491	0.36	1.17	3.25	0	1

Table 3. Intraclass correlation coefficients (ICC) of the multilevel models.

	Pressure irrigation systems	Scientific irrigation scheduling
Corn	0.743	0.073
Soybeans	0.838	0.114

Table 4. Results of multilevel models for the adoption of pressure irrigation systems by CORN farmers.

	Model 1: Random intercept only		**Model 2: M1+Level-1 Fixed Effects**		**Model 3: M2+Level-2 fixed effects**	
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Fixed Effects						
Intercept	3.7715***	0.7244	-4.0077***	0.4309	0.6291	3.7075
Water sources						
On-farm surface water only			0.0194	0.1289	-0.1127	0.1289
Off-farm surface water only			-1.6522***	0.1082	-1.4169***	0.1076
Two or more water sources			-0.1127*	0.0668	-0.1049	0.0668
Costs						
Cost for off-farm surface water($/acre-foot)			0.0016	0.0017	-0.0006	0.0016
Energy expenses ($/acre)			0.0009**	0.0004	0.0008**	0.0004
Facility expenses ($/acre)			0.0009***	0.0001	0.0010***	0.0000
Labor payment ($/acre)			-0.0194***	0.0019	-0.0201***	0.0020
Farm characteristics						
# of wells used			-0.0333***	0.0022	-0.0335***	0.0022
LN(total acre)			0.9052***	0.0263	0.9112***	0.0264
% of owned land			1.8020***	0.0685	1.8405***	0.0686
Federal assistance			0.0257	0.0627	0.0367	0.0630
Barriers to improvements						
Investigating improvement is not a priority			0.5163***	0.0671	0.5695***	0.0678
Risk of reduced yield or poorer quality crop			0.3077***	0.0967	0.3713***	0.0981
Limitation of physical field or crop conditions			0.1952**	0.0835	0.1488*	0.0833
Not enough to recover implementation costs			-1.1109***	0.0609	-1.1538***	0.0611
Cannot finance improvements			0.2714***	0.0719	0.2222***	0.0717
Landlords will not share improvement costs			-0.6715***	0.0683	-0.6950***	0.0683
Uncertainty about future water availability			0.4674***	0.0858	0.5048***	0.0864
Will not be farming long enough			-0.2934***	0.0924	-0.2791***	0.0931

Will increase management time or cost			-0.3545***	0.0743	-0.3015***	0.0746
Information sources						
Extension agents			0.1498***	0.0521	0.1725***	0.0523
Private irrigation specialists			0.1161***	0.0489	0.1117**	0.0490
Irrigation equipment dealers			0.5096***	0.0555	0.5479***	0.0559
Local irrigation district employee			0.5795***	0.1034	0.6424***	0.1054
Government specialists			-0.0407	0.0696	-0.0263	0.0702
Media reports			0.3627***	0.0871	0.3759***	0.0876
Neighboring farmers			-0.1653***	0.0578	-0.1388**	0.0581
E-information services			0.7675***	0.0704	0.7836***	0.0709
State-level variables						
PrecipChange2011					-0.0866	0.0744
PrecipChange2012					-0.0875***	0.0333
TempChange2011					-0.7447	0.7937
TempChange2012					1.4864**	0.7205
Midwest					1.9815	1.4105
South					-2.7473*	1.5679
Error Variance						
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Intercept	9.5100***	3.6771	2.8520***	0.4880	2.7499***	0.6371
Fit Statistics						
N	4761		4761		4761	
AIC	20177		15654		15644	
AICC	20177		15655		15645	
BIC	20179		15686		15672	

Significance level: * 10%; ** 5%; *** 1%

Table 5. Results of multilevel models for the adoption of pressure irrigation systems by SOYBEAN farmers.

	Model 1: Random intercept only		**Model 2: M1+Level-1 fixed effects**		**Model 3: M2+Level-2 fixed effects**	
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Fixed Effects						
Intercept	5.2722***	1.2983	1.6038*	0.8354	1.7930	7.1367
Water sources						
On-farm surface water only			-0.4028***	0.1289	-0.3951***	0.1290
Off-farm surface water only			-2.2426***	0.1676	-2.3513***	0.1690
Two or more water sources			-0.3340***	0.0662	-0.3436***	0.0662
Costs						
Cost for off-farm surface water($/acre-foot)			-0.0170***	0.0014	-0.0167***	0.0014
Energy expenses ($/acre)			0.0006	0.0009	0.0006	0.0009
Facility expenses ($/acre)			0.0004***	0.0000	0.0005***	0.0000
Labor payment ($/acre)			-0.0331***	0.0025	-0.0326***	0.0025
Farm characteristics						
# of wells used			-0.0489***	0.0027	-0.0493***	0.0027
LN(total acre)			0.5686***	0.0294	0.5796***	0.0295
% of owned land			0.0260	0.0657	0.0294	0.0658
Federal assistance			0.5568***	0.0576	0.5600***	0.0577
Barriers to improvements						
Investigating improvement is not a priority			0.3250***	0.0648	0.3340***	0.0649
Risk of reduced yield or poorer quality crop			0.7689***	0.0977	0.7886***	0.0980
Limitation of physical field or crop conditions			0.4142***	0.0790	0.4189***	0.0791
Not enough to recover implementation costs			-1.5141***	0.0578	-1.5224***	0.0579
Cannot finance improvements			0.3449***	0.0719	0.3560***	0.0720
Landlords will not share improvement costs			-0.7132***	0.0660	-0.7094***	0.0661
Uncertainty about future water availability			-0.2793***	0.0881	-0.2873***	0.0882
Will not be farming long enough			-1.0287***	0.0994	-1.0150***	0.0995

Will increase management time or cost			0.7224***	0.0894	0.7053***	0.0894
Information sources						
Extension agents			0.2121***	0.0470	0.2072***	0.0470
Private irrigation specialists			0.8294***	0.0484	0.8294***	0.0485
Irrigation equipment dealers			0.1631***	0.0533	0.1551***	0.0533
Local irrigation district employee			0.5807***	0.1044	0.6324***	0.1052
Government specialists			0.1901***	0.0653	0.1991***	0.0654
Media reports			1.0754***	0.0772	1.0830 ***	0.0773
Neighboring farmers			-0.5489***	0.0549	-0.5622***	0.0550
E-information services			0.0351	0.0646	0.0297	0.0648
State-level variables						
PrecipChange2011					-0.3109***	0.1339
PrecipChange2012					-0.2897***	0.1260
TempChange2011					0.2378	1.5937
TempChange2012					0.2224*	0.1267
Midwest					0.7937	2.7470
South					-3.2851	2.7024
Error Variance						
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Level 2 Intercept	17.0582**	8.8834	8.5230***	2.1608	7.8684***	2.6921
Fit Statistics						
N	3491		3491		3491	
AIC	18658		15268		15239	
AICC	18658		15269		15240	
BIC	18660		15299		15277	

Significance level: * 10%; ** 5%; *** 1%

Table 6. Results of multilevel models for the adoption of scientific irrigation scheduling practices by CORN farmers.

	Model 1: Random intercept only		**Model 2: M1+Level-1 fixed effects**		**Model 3: M2+Level-2 fixed effects**	
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Fixed Effects						
Intercept	-0.8645***	0.1142	-3.8559***	0.1877	-1.5974*	0.8882
Water sources						
On-farm surface water only			-1.5954***	0.1036	-1.3186***	0.0985
Off-farm surface water only			0.3334***	0.0857	0.3684***	0.0860
Two or more water sources			0.1544***	0.0477	0.1724***	0.0479
Costs						
Cost for off-farm surface water($/acre-foot)			0.0053***	0.0012	0.0053***	0.0012
Energy expenses ($/acre)			-0.0004*	0.0002	-0.0003	0.0002
Facility expenses ($/acre)			0.0021***	0.0001	0.0022***	0.0001
Labor payment ($/acre)			0.0231***	0.0024	0.0232***	0.0024
Farm characteristics						
# of wells used			0.0058***	0.0018	0.0057***	0.0018
LN(total acre)			0.2369***	0.0164	0.2620***	0.0164
% of owned land			0.0270	0.0436	0.0648	0.0438
Federal assistance			0.3648***	0.0389	0.3406***	0.0390
Barriers to improvements						
Investigating improvement is not a priority			-0.0620	0.0418	-0.0409	0.0419
Risk of reduced yield or poorer quality crop			0.2608***	0.0592	0.2884***	0.0593
Limitation of physical field or crop conditions			1.3096***	0.0575	1.3431***	0.0577
Not enough to recover implementation costs			0.0132	0.0426	0.0217	0.0427
Cannot finance improvements			-0.1347***	0.0479	-0.1374***	0.0480
Landlords will not share improvement costs			0.0541	0.0511	0.0410	0.0512
Uncertainty about future water availability			0.0755	0.0517	0.0804	0.0518
Will not be farming long enough			-0.3354***	0.0646	-0.3636***	0.0649

Will increase management time or cost			-0.6204***	0.0621	-0.6624***	0.0627
Information sources						
Extension agents			0.7084***	0.0334	0.7039***	0.0335
Private irrigation specialists			1.5440***	0.0322	1.5532***	0.0323
Irrigation equipment dealers			0.2149***	0.0345	0.2234***	0.0346
Local irrigation district employee			0.5308***	0.0673	0.4873***	0.0674
Government specialists			0.7990***	0.0468	0.7959***	0.0468
Media reports			0.2940***	0.0506	0.3016***	0.0507
Neighboring farmers			-0.3176***	0.0400	-0.2967***	0.0400
E-information services			0.9189***	0.0402	0.9416***	0.0403
State-level variables						
PrecipChange2011					-0.0397**	0.0173
PrecipChange2012					-0.0497*	0.0280
TempChange2011					0.6835***	0.1876
TempChange2012					0.7486***	0.2819
Midwest					0.4262	0.3025
South					-1.5179***	0.3738
Error Variance						
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Level 2 Intercept	0.2587***	0.0840	0.3447***	0.0942	0.1466***	0.0536
Fit Statistics						
N	4761		4761		4761	
AIC	39569		29710		29686	
AICC	39569		29710		29687	
BIC	39571		29741		29724	

Significance level: * 10%; ** 5%; *** 1%

Table 7. Results of multilevel models for the adoption of scientific irrigation scheduling practices by SOYBEAN farmers.

	Model 1: Random intercept only		**Model 2: M1+Level-1 fixed effects**		**Model 3: M2+Level-2 fixed effects**	
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Fixed Effects						
Intercept	-0.9981***	0.1492	-4.0243***	0.2645	-2.0738*	1.1882
Water sources						
On-farm surface water only			-1.2501***	0.1335	-1.2311***	0.1331
Off-farm surface water only			0.5887***	0.1241	0.5744***	0.1238
Two or more water sources			0.4622***	0.0673	0.4648***	0.0673
Costs						
Cost for off-farm surface water($/acre-foot)			-0.0042***	0.0012	-0.0044***	0.0011
Energy expenses ($/acre)			0.0095***	0.0008	0.0095***	0.0008
Facility expenses ($/acre)			0.0001	0.0001	0.0001	0.0001
Labor payment ($/acre)			0.0229***	0.0030	0.0228***	0.0030
Farm characteristics						
# of wells used			0.0084***	0.0024	0.0088***	0.0024
LN(total acre)			0.1341***	0.0241	0.1246***	0.0241
% of owned land			-0.0982*	0.0598	-0.0928	0.0598
Federal assistance			0.4414***	0.0479	0.4435***	0.0479
Barriers to improvements						
Investigating improvement is not a priority			-0.1247**	0.0557	-0.1237**	0.0557
Risk of reduced yield or poorer quality crop			0.2099***	0.0798	0.2036***	0.0798
Limitation of physical field or crop conditions			1.1293***	0.0720	1.1362***	0.0720
Not enough to recover implementation costs			0.0023	0.0520	-0.0067	0.0520
Cannot finance improvements			0.2610***	0.0648	0.2670***	0.0648
Landlords will not share improvement costs			-0.0416	0.0612	-0.0388	0.0612
Uncertainty about future water availability			0.3021***	0.0782	0.3001***	0.0781
Will not be farming long enough			-0.1621*	0.0888	-0.1884**	0.0888

Will increase management time or cost			-0.6123***	0.0908	-0.5830***	0.0905
Information sources						
Extension agents			0.9781***	0.0412	0.9821***	0.0411
Private irrigation specialists			1.4865***	0.0403	1.4868***	0.0402
Irrigation equipment dealers			0.1803***	0.0442	0.1741***	0.0442
Local irrigation district employee			-0.2824***	0.0928	-0.2424***	0.0928
Government specialists			0.9722***	0.0566	0.9666***	0.0566
Media reports			0.1906***	0.0607	0.1921***	0.0607
Neighboring farmers			-0.0561	0.0492	-0.0625	0.0491
E-information services			0.9108***	0.0504	0.9083***	0.0504
State-level variables						
PrecipChange2011					-0.0183	0.0220
PrecipChange2012					-0.0264	0.0355
TempChange2011					0.8408***	0.2544
TempChange2012					0.3524	0.3725
Midwest					0.4262	0.3919
South					-1.4101***	0.5006
Error Variance						
	Estimate	***Std Err***	***Estimate***	***Std Err***	***Estimate***	***Std Err***
Level 2 Intercept	0.4218***	0.1425	0.7672***	0.2338	0.2310**	0.1010
Fit Statistics						
N	3491		3491		3491	
AIC	25095		18479		18467	
AICC	25095		18479		18468	
BIC	25097		18510		18505	

Significance level: * 10%; ** 5%; *** 1%

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