AGRICULTURAL AND WATER USE IN THE WEST

by

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STATEMENT BY AUTHOR

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(SHAILAJA DEVA)

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ABSTRACT

This thesis presents three separate analyses of irrigator behavior using data from the U.S. Department of Agriculture's Farm and Ranch Irrigation Survey (FRIS). One chapter examines descriptive data from the 2003 FRIS for the state of Arizona. Main findings are that irrigation water applications vary significantly by irrigation method and by choice of crop. Also, 25 percent of irrigators account for 97 percent of water use, so programs to encourage adoption of improved irrigation practices and technologies will have a greater impact on overall water use if they target these irrigators. Irrigators who currently account for more than 400,000 acre-feet of irrigation applications report that they may discontinue farming. Another chapter uses nonparametric measures of association to examine the relationship between farm size and irrigator behavior using special tabulations from the 1998 FRIS survey. Irrigator use of information, irrigation scheduling methods, investigation of irrigation improvements and participation in conservation programs all vary systematically and significantly with farm size. Finally, 1998 special tabulation data from the 1998 FRIS are used to explain variations across farm size class and state in the adoption of sprinkler irrigation among 17 western states. The extent of sprinkler adoption is greater among very large farms, among farms relying more on groundwater, in areas with more sheet and rill erosion, in areas with more months of freezing weather, and among farms greater pumping costs.

CHAPTER 1

Introduction

Water is one of the most important and limiting resources for agriculture in the western United States. Irrigation accounts for 80% of water withdrawals in Arizona and 88% of withdrawals in New Mexico (Hutson et al. 2004). Owing to the increase in population, competition for water among agricultural, thermoelectric, industrial and municipal water users is increasing. With little or no new surface supply development and declining ground water tables, increasing competition for western water resources must be resolved through more efficient allocation and conservation. Because agriculture is the major user of water in the Western United States, there is a need for agriculture to conserve water to meet the growing demands from other sectors.

Adoption of improved irrigation technologies and management practices is one ways to conserve water. Knowledge about how irrigators use information, make irrigation decisions, and make investments in new technology is important to determine what the potential gains from adoption are and what constraints different irrigators face.

Objectives

In this thesis, I attempt to answer the following research questions:

- What information sources do irrigators rely on to make water management decisions?
- What methods and technologies do they use to decide when to irrigate?
- What are major barriers to investment in water or energy conserving irrigation systems?
- To what extent do irrigators participate in government programs that subsidize adoption of irrigation and drainage improvements?
- Does irrigator use of information, investment and conservation program participation vary systematically by farm size?
- How do climate, soil, price, and other factors affect the adoption of sprinkler irrigation systems in the West?

Scope of the Study

The results of this study would be useful in understanding the structure of agriculture in the Southwest and water use by different farms. It may also give policy makers a clearer idea about the groups that are to be targeted to adopt improved irrigation technologies. The information developed in this study will also be valuable for understanding the nature and extent of effect of climatic factors in adoption of irrigation systems.

Plan of Thesis

The remainder of this thesis is presented in three chapters. Chapter Two discusses some findings from the U.S. Department of Agriculture’s (USDA’s) 2003 Farm and Ranch Irrigation Survey (FRIS), focusing on results for Arizona. Chapter Three analyzes the association between key irrigation management variables and farm size in Arizona and New Mexico using data from an earlier (1998) FRIS. The chapter demonstrates how nonparametric measures of association can be used to examine the relationship between farm size and irrigator behavior. Chapter Four conducts multivariate regression analysis to examine factors affecting the adoption of sprinkler irrigation systems in 17 western states using 1998 FRIS data. The three chapters each make use of different types of Farm Ranch Irrigation Survey data, at different levels of regional detail and scope.

CHAPTER 2

Irrigation and Water Management Practices in Arizona:

Results from the 2003 Farm and Ranch Irrigation Survey

Introduction

Results of the 2003 Farm and Ranch Irrigation Survey (FRIS) were first made public in November 2004. The 2003 FRIS is the sixth survey devoted entirely to the collection of on-farm irrigation data for the United States. The 2003 FRIS—a follow-on survey to the 2002 Census of Agriculture—provides an extensive and comprehensive picture of irrigation practices and water use at the national and state level. This chapter presents a sample of the types of information for Arizona available online from the survey.

Agriculture is the major user of water in the western United States, accounting for 83% of total use (Schaible, et al. 1991). Owing to increasing population, demand for water is increasing for municipal, industrial, and environmental uses. One way to meet this increased demand for water is to divert some portion of agriculture water to other uses. Agricultural producers can reduce water use by shifting to crops with lower water requirements or by adopting improved irrigation technologies. Modern irrigation technologies allow more frequent irrigation with smaller volumes of water. The distribution of water is more uniform, less water is lost to evaporation, deep percolation and runoff and soil erosion is reduced (EESI 1997). With more uniform and timely application of water, more crops can be produced with less water. According to Kimmell, 4.5 million acre-feet are saved each year by the use of more sophisticated irrigation technologies. This water savings is equivalent to the water use of every woman, man, and child in the 29 largest cities in United States. Large farms account for most of the water use in the western United States. Knowing the barriers in adoption of improved irrigation technology by these farms will help in formulating suitable policies to motivate these farms to adopt new technology thereby conserving more water.

Background

The United States Constitution requires that a census of population be conducted every 10 years. In 1840, the census began collecting more detailed information about agriculture. Irrigation data have been collected from farms and ranches in the census of agriculture since 1890. The 2003 survey is the most recent, but surveys from 1998 and 1994 are also available online.

Changes in Irrigated Acres

Acres receiving irrigation applications in Arizona fell over 4 percent between the 1998 and 2003 surveys. Figure 2.1 shows changes in irrigated acres for selected crops in the state. Grains, cotton, and orchards and nuts experienced the greatest declines in acreage, while vegetables, alfalfa, other hay, and corn silage had gains in acreage. The 1996 farm bill increased planting flexibility, allowing growers to substitute between field crops without being penalized with lower commodity program payments.

The growth in Arizona’s dairy industry has contributed to the growth in alfalfa, hay, and corn silage production in the state. Between 1998 and 2003, Arizona dairy herds increased by 18 percent and milk production increased 35 percent.

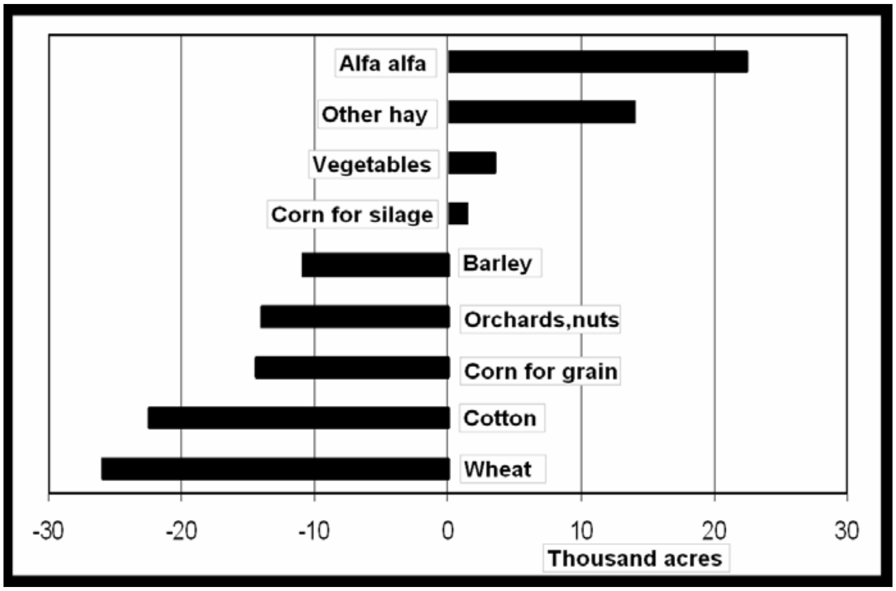


Figure 2.1: Change in Harvested Acres for Selected Arizona Crops, 1998-2003

Applications and Application Rates

In 2003, 836,587 acres in Arizona were irrigated with applications of 3.75 million acre feet of water. An acre foot is the amount of water needed to cover an acre, one foot deep in water. One acre foot equals 325,851 gallons and 1 million gallons equal 3.07 acre feet. Applications are respondents’ estimates of water applied to crops and do not measure total water withdrawn from surface and groundwater sources.

By way of comparison, the U.S. Geological Survey estimates that 6 million acre feet were withdrawn for irrigation in 2000. Applications also do not measure conveyance losses, return flows of irrigation water back to aquifers and water bodies, or consumptive use—the amount of withdrawn water lost to evaporation, plant transpiration, and incorporated into products or crops. That said, approximately 4.5 acre feet were applied per acre on Arizona's irrigated crops and pastures in 2003. Application rates (acre feet per acre or AF/acre) vary substantially by crop and year. Figure 2.2 compares application rates for selected Arizona crops for 1998 and 2003, the two most recent FRIS years. Rates vary from 2.5 AF/acre for barley in 1998 to 5.8 AF/acre for alfalfa in 2003.

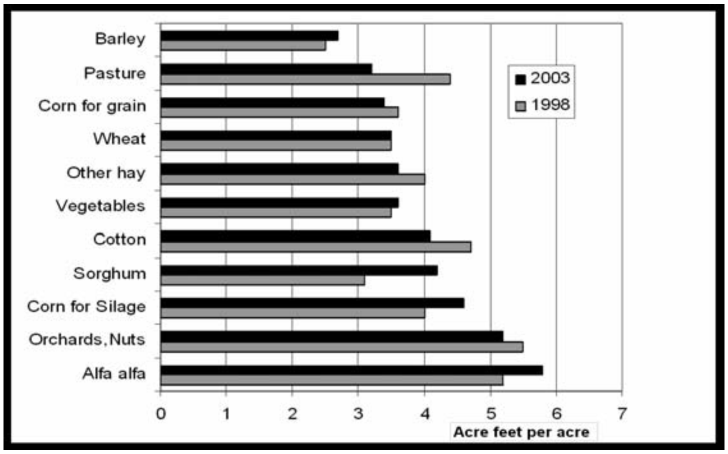


Figure 2.2: Water Application Rates for Selected Crops in Arizona, 1998 and 2003 (Acre Feet per Acre)

Application rates also vary greatly by irrigation technology. Sprinkler and drip systems can apply water more efficiently than gravity systems. Gravity flow systems are the dominant irrigation systems in the state. With gravity systems, water is conveyed to the field using open ditches or pipe, and released along the upper end of the field through siphon tubes, ditch gates, or pipe valves. About 90 percent of Arizona's acreage was irrigated with gravity systems, while farms relying solely on gravity systems accounted for 68 percent of irrigated acreage. Farms relying solely on sprinkler irrigation applied an average of 3.4 AF/acre but accounted for only 8 percent of irrigated acres in the state.

Farms relying solely on drip irrigation also applied 3.4 AF/acre on average, but accounted for less than 2 percent of irrigated acreage.

Water Use Varies by Farm

In 2003, 699 farms—25 percent of farms in the state— applied 500 or more acre feet of water each (figure 2.3). These farms applied 97 percent of Arizona's irrigation water. The remaining 75 percent of farms (2,078 in all) applying less than 500 acre feet accounted for 3 percent of all irrigation applications. Farms applying 2,000 acre feet or more accounted for 16 percent of farms, but 89 percent of irrigation water applied.

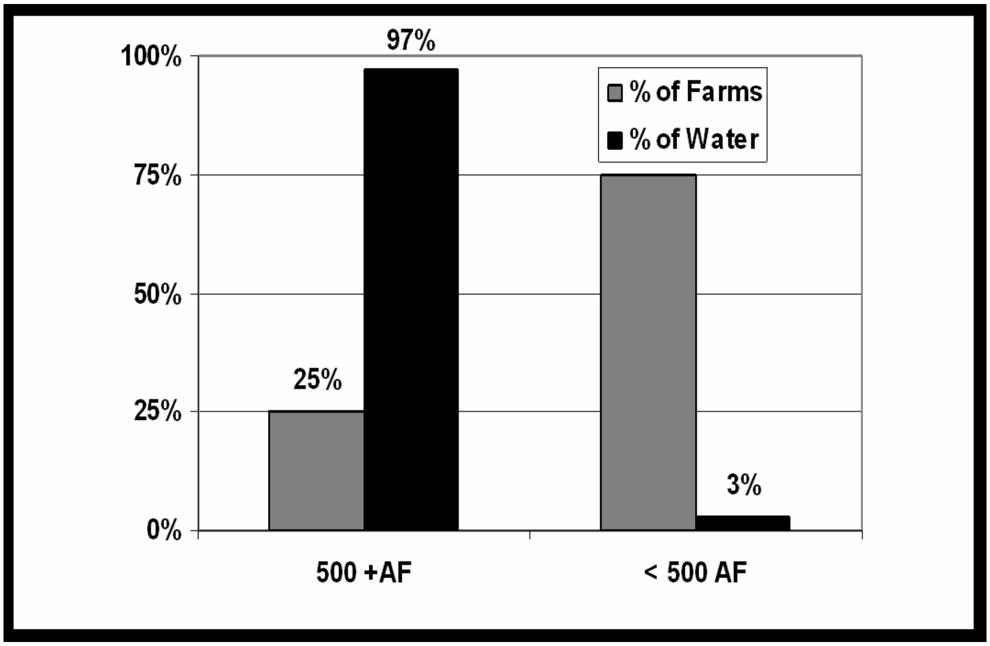


Figure 2. 3: One-Quarter of Farms Apply 97 % of Arizona's Irrigation Water

Because farms vary so much in their contribution to overall water use, one must exercise care in measuring farm-level irrigation behavior. To get a clear picture of overall water management patterns, it is important to capture the importance of those farmers accounting for most of the irrigation. In the figures reported next, are weighted responses by the amount of water applied or the number of acres irrigated.

Irrigation Investments

In 2003, Arizona farms invested over $21 million in irrigation equipment, facilities, land improvement, and computer technology. Of this, $11.2 million went to replace old equipment, $6.7 went to water conservation investments, and $3.2 million went to new expansions.

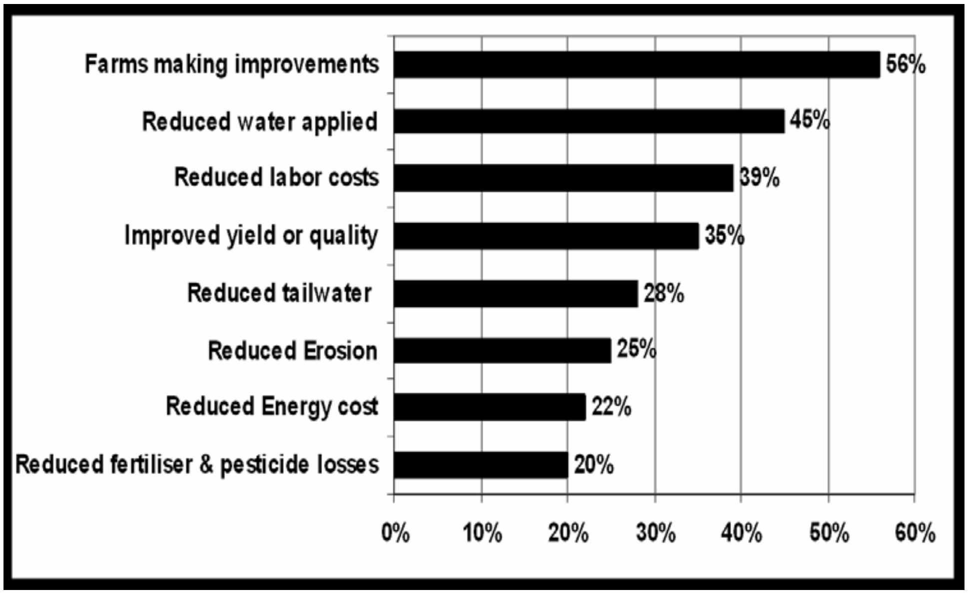


Figure 2. 4: Effects of Conservation Improvements in Previous Five Years (By Share of Arizona Irrigation Water Use)

The survey asks farmers and ranchers if they have implemented any energy or water conservation improvements over the last five years. Figure 2.4 summarizes responses weighted by the amount of irrigation water farms applied. Respondents that accounted for 56 percent of water applied made conservation improvements in the last five years. Figure 2.4 also shows what respondents thought the effects of those improvements were. Respondents could choose more than one project and effect. Respondents accounting for 45 percent of water applied made improvements that reduced water applications. Other important effects were reduced labor costs (39%), energy costs (22%) and improved crop yield or quality (35%). The average cost of water purchased from off-farm sources was about $72 per acre (or $16/AF). Irrigation labor costs ran about $47 per acre, while energy pumping costs averaged $25/acre for surface water and $92/acre for groundwater. Investments were also made that improve environmental quality. These include investments to reduce soil erosion (25%), fertilizer and pesticide losses (20%) and tailwater, the runoff from the lower end of an irrigated field (28%).

Barriers to Conservation

Farmers were also asked about barriers to making improvements in conserving energy or water. In all, respondents accounting for 1.6 million acre feet applied— 44 percent of the state total — reported that they faced some barrier to conservation improvements. This is up from 41 percent in the 1998 survey. Figure 2.5 shows a breakdown by barrier for those farmers facing constraints. Again, percentages are weighted by water applied. Of farms facing barriers to conservation improvements, the most common barriers are financial. Farms accounting for 47 percent of water applied could not finance improvements.

Other economic reasons given were that landlords would not share the cost of improvements (43%) and that reduced costs from conservation would not outweigh the initial installation costs (38%). Farmers accounting for only a small share of water use thought investigating improvements were not a priority (10%), while others cited physical field constraints (22%) and concern about reduced crop yield or quality (23%).

Because irrigation investments require large up-front costs, growers must anticipate farming long enough to re-coup these initial outlays. Other barriers to adoption were uncertainty about future water availability (31%) and operators' belief that they will not be farming long enough to justify improvements (30%). Of 2,777 farms, 63 responded that they will not be farming long enough to justify improvements. These 63 operations applied 486,647 acre feet of water in 2003

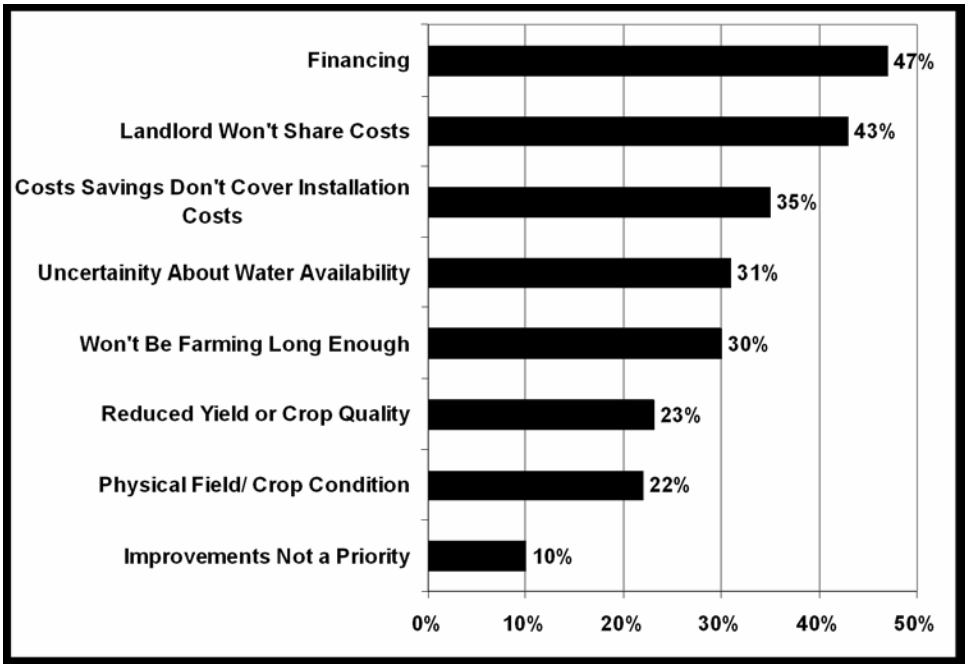


Figure 2. 5: Barriers to Making Improvements to Lower Energy Costs or Conserve Water (By Percentage of Water Applied by Farms Facing Barriers)

Information to Reduce Costs and Conserve Water

The FRIS survey also asked farmers what sources of information they relied upon to reduce irrigation costs or conserve water. Figure 2.6 provides a breakdown of responses weighted by irrigated acres. Farmers could rely on more than one source.

The two most common sources were neighboring farmers (51%) and extension agents and university specialists (48%). Next in importance was staff of USDA’s Natural Resources Conservation Service (NRCS) and other federal, state, or local agencies (33%). To a lesser extent, farmers relied on independent consultants, equipment dealers, and irrigation districts. Farmers accounting for 8 percent of irrigated acres relied on electronic (Internet-based) services.

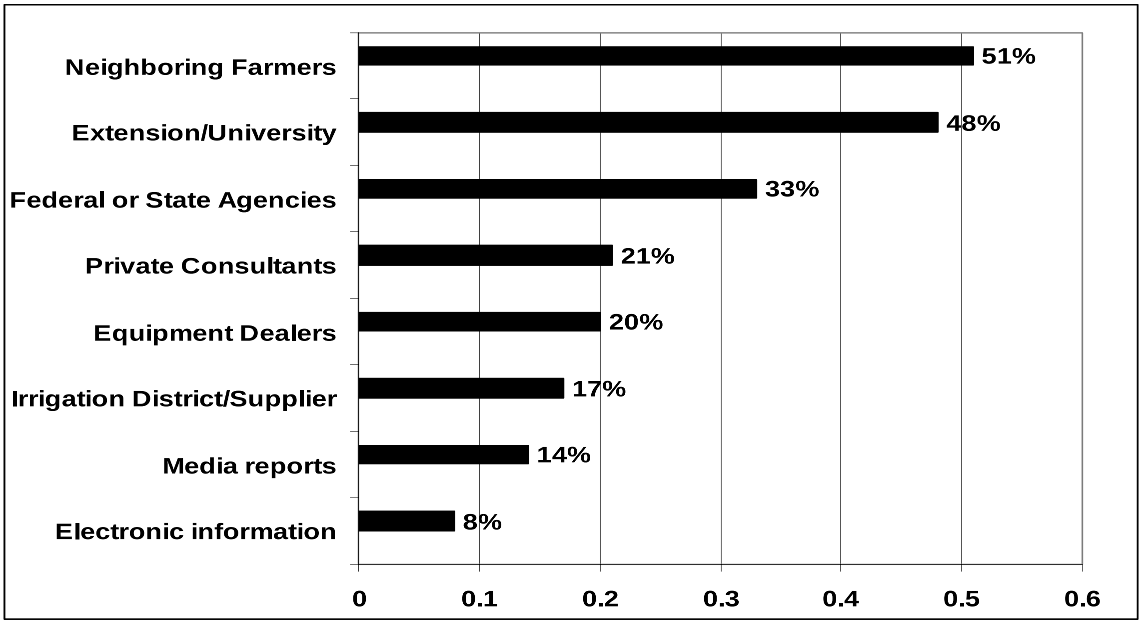


Figure 2. 6: Sources of Information Relied Upon to Reduce Irrigation Costs

Conclusions

This chapter has presented an overview of basic water use statistics for the state of Arizona from the 2003 Farm and Ranch Irrigation Survey (FRIS). To conclude, this section discusses how these basic statistics relate to a number of water policy questions.

First, what is the potential to use water more efficiently by choosing different technologies or management practices? Water application rates vary widely by irrigation technology. About 90% of Arizona acreage is irrigated with the gravity method and statewide application rates are 4.5 acre-feet per acre. In contrast, farms relying solely on drip or solely on sprinkler irrigation apply only 3.4 acre-feet per acre. So, there is the technological potential to save substantial amounts of water by switching to these two pressurized irrigation systems. If there is technological potential to use less water, this raises additional questions about what barriers, economic or other, might exist that prevent further adoption.

Second, what is the potential to use water more efficiently by choosing different crops? Water requirements differ greatly from crop to crop. While application rates for barley, corn, wheat, and vegetables range from 2.5-3.6 acre-feet per acre, crops like alfalfa, nuts, and fruits apply more than 5 acre-feet per acre. Cotton lies in the middle, using 4.0-4.5 acre-feet per acre. Producers’ choice of crop, therefore, can have a large impact on overall water use. While state agricultural water conservation programs implemented by the Arizona Department of Water Resources have focused on choices of irrigation technologies and practices, crop choice may be just as important (if not more important) in affecting overall agricultural water use. Producers’ crop choices will depend on costs of production, prices received for different crops, and government programs that support output prices. The U.S. Cotton Program currently supports the price, and encourages greater production, of cotton. The Cotton Program has been successfully challenged by Brazil in a formal World Trade Organization dispute and there are current policy discussions about changing current U.S. farm programs to comply with WTO rulings. One possible measure would be to remove the remaining coupled payments that cotton farmers receive. Another measure would be removing restrictions on the planting of vegetables on base acres receiving commodity program payments. These policy changes, if enacted, could have important implications for overall water use depending on how farmers shift between acreage of different crops. For example, a shift from cotton to alfalfa or from barley to vegetables could mean more water use, while a shift from cotton to vegetables would mean less water use.

The 2002 Farm Bill included a Ground and Surface Water Conservation initiative under Environmental Quality Incentive Program (EQIP) that included cost-share payments, incentive payments, and loans for irrigation improvements, conversion to less water-intensive crops, and dryland farming (USDA, NRCS 2003). While dryland farming is not practical in Arizona, incentive payments to switch to less water intensive crops do have the potential to alter water use.

What do the FRIS results mean for water conservation programs? In Arizona, 25 percent of the farms apply 97 percent of the irrigation water. The largest farms are the heaviest users of water, so cost share programs would be more effective if they targeted on these groups of farms. The two sources of information that farmers used most for water management decisions were Cooperative Extension and neighboring farmers. This suggests that extension still has a role to play in transferring technology. The fact that so many farmers rely on their neighbors for information suggests that on-farm demonstrations by extension would be an effective technology transfer strategy.

What are the barriers to adopting more efficient irrigation technologies? Farms accounting for 44 percent of the state's irrigation water applied did not report making any water or energy conservation improvements in the previous five years. This, combined with the dominance of gravity irrigation suggests that there is a lot of technological scope for improving irrigation efficiency. Why then aren't farmers adopting improved practices? The main reasons cited were financial, either lack of financing or the perceived costs outweighed benefits. Another important reason cited was supply uncertainty. Management of groundwater and drought as well as water transfers and irrigation district operation could affect technology adoption to the extent that they increase or decrease uncertainty.

Finally, farms which account for 486,000 acre feet of water responded that they didn't invest in improved technologies because they did not expect to be farming in future. According to the most recent U.S. Geological Survey estimates, water use for domestic uses (residential uses) was about 0.25 AF per person in 2000 (Hutson 2004). The FRIS survey questions do not indicate whether farmers who think they will discontinue farming are planning to sell their land for urban development. However, if all the water currently used by these operations were diverted to urban use, it would (at current use rates) be equivalent to water use by over 1.9 million people.

Chapter 3

Farm Size and Irrigation Practices in Arizona and New Mexico

This chapter discusses the association between key water management variables and farm size. The effectiveness of extension and technology transfer programs to improve irrigation efficiency may well depend on the underlying farm structure in a region. The New Mexico's Governor's Blue Ribbon Water Task Force reports:

> *"[A]gricultural water conservation will become increasingly important as a critical source of additional water supply to meet growing water demands for municipal/urban, industrial, recreation, endangered species and ecosystem health, and Native American trust responsibilities. Farm size patterns likely influence the effectiveness of water conservation programs."*

Leib et al. (2002) found significant positive relationships between farm size and adoption of scientific irrigation scheduling methods (use of crop evapotranspiration data and soil moisture testing) among Washington state farmers. Skaggs and Samani (2005) in a study of Elephant Butte Irrigation District in New Mexico found a "lack of interest in making improvements to current irrigation systems or methods on the smallest farms (page 43)."

This chapter examines data from Arizona and New Mexico to test hypotheses about the relationship between farm size and farmer / rancher behavior. These include:

- Sources of information used to make irrigation decisions
- Methods used to determine the timing of irrigation
- Barriers to adoption of improved irrigation technology

- Participation in government cost-share programs to improve irrigation efficiency

Data

The data for the study is based on special tabulations of the 1998 Farm and Ranch Irrigation Survey made available by USDA’s Economic Research Service (http://ers.usda.gov/Data/WesternIrrigation/ShowTables.asp) (Schaible 2004a). Data is available in cross-tab form and contains several categorical variables related to farmer and rancher irrigation practices. This data include several “yes-no” responses about use of information, technology, investments, and participation in conservation programs. The ERS special tabulations break down responses by four farm sales classes:

- small farms < $100,000
- medium farms $100,000 to < $250,000
- large farms $250,000 to < $500,000
- very large farms $500,000 or greater

This study focuses on data from Arizona and New Mexico. The data from the special tabulations and more general FRIS data are organized in a set of cross-tabs that show relationships between two variables, such as between farm size and participation in EQIP, or irrigation source and commodity grown. Because the tables focus on 2 X 2 relationships, they do not lend themselves easily to standard multivariate regression analysis. For this reason, relatively little statistical analysis has been carried out using the FRIS data. Much of this has been done by USDA researchers who have easier access to the farm-level survey responses. While FRIS data is often used for descriptive, outreach publications about irrigation management, less has been done to formally test hypotheses about farm structure – irrigation relationships. For example Schaible (2004 b) and ERS web-based reports, discuss relationships between farm size classes and irrigation practices, but do not test the statistical significance of relationships. It is possible, however, to use non-parametric tests of association to test hypotheses about the relationship farm size and irrigator behavior. These methods can be used to test both the strength and statistical significance of association between farm size and irrigator behavior.

Methods: Measures of Association for Contingency Tables

The data from the special FRIS tabulations can be arranged as a set of 4 X 2 contingency tables with four rows for each farm size class and two columns, one representing a "no" response to a survey question and the other a "yes" response. For example, farmers were asked to respond yes or no to whether or not they received cost-share payments for irrigation or drainage improvement's through USDA's Environmental Quality Incentive Program (EQIP). Results for Arizona are shown in table 3-1.

Table 3-1: Farms participating in the EQIP program in previous 5 years, Arizona

Farm size	No	Yes	Percent responding yes
Small	1661	18	1
Medium	203	13	6
Large	246	33	12
Very Large	343	120	26

Source: Farm Ranch and Irrigation Survey, 1998 (USDA, NASS)

There appears to be a definite positive association between farm size and EQIP participation. Only 1 percent of small farms reported participating in EQIP, while rates increase for each larger farm size class. Another question asks farmers if they rely on extension agents or university specialists for water management information. Table 3-2 shows results for Arizona.

Table 3-2: Farmers who report relying on extension agents or university specialists for water management information, Arizona

Farms	No	Yes	Percent responding yes
Small	1163	515	31
Medium	118	98	45
Large	140	139	50
Very Large	278	186	40

Source: Farm Ranch and Irrigation Survey, 1998 (USDA, NASS)

Here the relationship between farm size and information use is not so obvious. Small farms have lower use rates than the other larger farm size classes, but the very large farm category has lower use rates than the middle two size classes.

It would be useful to have a method for measuring the strength of the association between farm size and different yes-no responses. The commonly used (Pearson) correlation coefficient assumes that two variables have a bivariate normal distribution and are measured numerically.

The cases in the tables above are categorical (farm size class and yes/no). One could also treat the variables as ordinal. This is easy to see for farm size classes, moving from small to larger classes. The yes-no responses, can be thought of as binary with 0 for no and 1 for yes (as in a logit or probit model). The category “yes” can be considered “higher” than the category “no.” One can give an economic interpretation to binary responses that give them an order. For example, one would expect farmers to participate in EQIP if the expected benefit (in terms of profit or utility) were positive and zero otherwise. The "yes" response to EQIP participation would then indicate a positive expected payoff from participation, while a "no" response would indicate zero or negative expected payoff.

A common test for association for contingency tables (and a standard one presented in mathematical statistics texts) is the Chi-squared test. The Chi-squared test's null hypothesis is that there is independence (no association) between two variables represented in a contingency table. The alternative hypothesis is that the variables are not independent, but does not specify any particular association. Gibbons (1993) points out a number of problems with the Chi-squared test. First, even for large sample sizes, the test statistic's distribution is only approximately Chi-squared. The true distribution is unknown. Second, the Chi-squared test doesn't allow for testing a particular type of association against a null. For example, it doesn't specifically test a positive (or negative) relationship between variables against the null hypothesis. Third, when some cells have few observations relative to the total (small expected frequencies) the test statistic becomes inflated. Gibbons warns "the test almost always leads to rejection of the null if the sample size is large (p. 61)." Fourth, the Chi-squared test is not appropriate for ordinal data because the test is independent of the ordering of rows and columns. For example, in Table 3-1, the Chi-squared test statistic would be the same no matter what order farm size classes were placed. For a test of association, one would want the order of variables to matter.

The Goodman-Kruskal Gamma (γ)

One alternative to the Chi-squared test is the Goodman-Kruskal gamma (γ) coefficient. The γ coefficient is a non-parametric measure of association between two ordinal variables. As with the correlation coefficient, values range from +1 (for positive association) to –1 (for negative association). For complete independence, $\gamma = 0$, but γ can also equal 0 for non-monotonic associations. For example, γ can also equal 0 for u-shaped or inverted u-shaped relationships between variables.

The γ coefficient is computed as the ratio of the difference between concordant pairs C and discordant pairs D and the sum of concordant and discordant pairs. Tied pairs are excluded.

$$\gamma = (C - D) / (C + D)$$

Gamma differs from other measures of association (such as Kendall's τ_b) in the way it treats ties (Gibbons). To illustrate, let's look at the numbers in Table 3-2 again.

	Uses Extension Information	
Farms	**No**	**Yes**
Small	1163	515
Medium	118	98
Large	140	139
Very Large	278	186

To calculate concordant pairs for an r X 2 contingency table, where r = number of rows and 2 is the number of columns; pick a cell in left column and uppermost row. Concordant pairs with these 1163 observations are the sum of observations that are in a (lower row) and a rightward column, 1163 * (98 + 139 + 186) = 491949. Repeat for the next row in the left column. Concordant pairs are 118 * (139 + 186) = 38350. Repeat again for the left column, one row down. Concordant pairs are 140 * 186 = 26040. The sum of all concordant pairs is 491949 + 38350 + 26040 = 556339. Concordant pairs are pairs between cells where one cell is "to the <u>right</u> and down" from the other.

Discordant pairs are pairs between cells where one cell is to "to the <u>left</u> and down" from the other. So the discordant pairs are:

515 * (118 + 140 + 278) = 276,040

98 * (140 + 278) = 40,964

139 * 278 = 38,642

Sum = 276,040 + 40,964 + 38,642 = 355,646

Pairs are tied on columns if they share the same column and tied on rows if they share the same row. These pairs are excluded from the γ calculation:

$\gamma = (C - D) / (C + D)$

$\gamma = (556{,}339 - 355{,}646) / (556{,}339 + 355{,}646) = 0.22.$

For the values in Table 3-1 relating farm size to EQIP participation, γ is:

$\gamma = (336{,}305 - 33{,}232) / (336{,}305 + 33{,}232) = 0.82.$

So, the γ coefficient makes certain intuitive sense. There is a positive association between farm size and both participation in EQIP and with getting information from extension From Tables 3-1 and 3-2 it looks like there is a stronger positive association between farm size and EQIP participation ($\gamma = 0.82$) than to getting information from extension ($\gamma = 0.22$). But can we say anything more about the differences beside 0.82 is greater than 0.22?

According to Garson (2006), γ can be interpreted in terms of proportionate reduction in error (PRE). Consider two randomly chosen farm size – EQIP participation pairs. Suppose we know that the farm size class of second observation is greater than the first observation (in a lower row). Suppose now that (a) we want to predict the rank of the column of the second observation (where rank increases moving to the right), and (b) we know the column rank of the first observation. Now, what if we make a prediction based on the assumption that because the row of the second observation is below the first observation, then the column of the second observation will be to the right of the first observation? If $\gamma = 0.82$, following this strategy (predicting based on information about the rows) will reduce our errors in predicting the rank of the columns by 82% compared to assuming no association.

Table 3-3 shows different values for γ for nine different 3 X 3 contingency tables.

Table 3-3: Values for γ for different contingency tables

$\gamma = 1$			$\gamma = 0$			$\gamma = 0.4$		
3	0	0	1	1	1	2	0	1
0	3	0	1	1	1	1	1	1
0	0	3	1	1	1	1	0	2
$\gamma = -1$			$\gamma = 0$			$\gamma = -0.4$		
0	0	3	3	0	0	1	2	2
0	3	0	0	3	0	0	1	0
3	0	0	3	0	0	2	1	1

For the table where $\gamma = 1$, one can see that the decision rule above would reduce prediction error to zero. The same would apply for the table where $\gamma = -1$, except one would predict based on negative association. In the table where all cells have one observation, observations are uniformly distributed and $\gamma = 0$. There is no gain in prediction accuracy by assuming a positive of negative association. Note that $\gamma = 0$ in the table below the uniformly distributed one. It appears that there is a quadratic relationship between variables where the middle row has the highest column rank. Thus γ is a measure of monotonic association (positive or negative) and not one of every kind of association. The right two tables, show cases where knowing the relative ranks of rows of observations has less of an effect on reducing prediction error.

Test of Significance of γ

Exact tests of the significance level of γ require special tables (Goodman and Kruskal, 1980). Gibbons (1993) however, presents an approximate, normally distributed test statistic, Z where

$$Z = 3 \gamma [(n (r - 1) (c - 1)]^{1/2} / 2 [(r + 1) (c + 1)]^{1/2}$$

where n = number of observations, r = number of rows, and c = number of columns.

Cochran-Armitage Trend Test:

Another method for testing the significance of association is the Cochran–Armitage trend test (Agresti 2002). It is analogous to testing the significance of the slope coefficient β in a linear probability regression model. Let π_i be the probability of a “yes” response to a question by the *i*th farmer. Then a linear probability model would be

$$\pi_i = \beta \text{ (category score)}_i + \varepsilon_i$$

In our case, the categories are small farms, medium sized farms, large farms, and very large farms, which would be assigned numeric scores. The null hypothesis is $\beta = 0$, there is no linear trend between the category score (farm size) and the proportion of yes responses. The Cochran-Armitage trend test has a z-test statistic that is distributed normally. This test is for both significance and sign of the trend. This test statistic can be calculated in SAS (see tables below). The SAS output z-score is the negative of the trend when the binary response is in columns. We report –z scores so that a positive score represents a positive relationship. In general, the significance test for γ and the Cochran-Armitage z-scores provide consistent results for the test conducted.

Farm Size and Sources of Irrigation Information

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 (mark all that apply)? (USDA, NASS 2003). Options for response were:

1. Extension agents or university specialists
2. Government specialists
3. Irrigation equipment dealers
4. Irrigation district or water supplier
5. Media reports / press
6. Neighboring farmers
7. Private irrigation specialists or consultants

In both states there was a relatively strong positive association between farm size and reliance on private irrigation specialists and consultants with $\gamma = 0.81$ for Arizona and $\gamma = 0.93$ for New Mexico (Table 3-4). While use was still relatively low for even very large farms, it was virtually non-existent for small farms. In contrast there was a significant negative association between farm size and reliance on irrigation districts. There appears to be a stronger association between farm size and reliance on extension, university, and government sources in Arizona than in New Mexico. The dominant sources of information appear to be extension agents and university specialists, government specialists and neighboring farmers. Reliance on irrigation equipment dealers is greater in New Mexico and there is a stronger positive association between farm size and use of this source of information in New Mexico.

Table 3.4 Sources of Irrigation Information

Farm size	Extension agents or university specialists	Government specialists	Irrigation equipment dealers	Irrigation district / water supplier	Media reports / press	Neighboring farmers	Private irrigation specialists or consultants
Arizona							
(Values are percentage yes responses)							
Small	31	5	7	42	3	36	0
Medium	45	16	3	16	14	40	1
Large	50	30	6	9	10	32	10
Very Large	40	41	13	21	--	38	17
Gamma	0.22	0.72	0.21	-0.49	0.45	0.02	0.81
Gamma Z value	7.58	24.69	7.30	-16.72	15.37	0.61	25.61
Cochran-Armitage -z	5.59	20.55	3.99	-11.20	7.06	0.35	14.98
New Mexico							
Small	32	19	8	22	12	49	0.2
Medium	23	22	29	7	20	44	16
Large	36	29	22	10	16	35	11
Very Large	36	40	44	8	12	42	28
Gamma	-0.02	0.30	0.67	-0.52	0.15	-0.14	0.93
Gamma z value	-1.6655	22.47	49.10	-38.22	10.83	-10.46	68.68
Cochran-Armitage -z	-0.62	8.65	19.75	-7.65	1.54	-3.53	30.85

Significance level = 5% for | z | = 1.96; = 1% for | z | = 2.576; = 0.1% for | z | = 3.291;

Irrigation Scheduling

In the FRIS survey 1998, growers were asked, “how did you decide when to apply water in 1998?” Response options were:

1. Condition of crop by observation
2. Feel of the soil
3. Soil moisture sensing devices
4. Commercial scheduling services
5. Media reports on crop water needs
6. Water delivered in turn
7. Calendar schedule
8. Computer simulation models
9. Other practices

In addition, the Economic Research Service tabulated an additional, aggregate category, “most water-management-intensive and water-conserving means to decide when to apply water.” Farms were designated as falling into this category if they used any one of the following methods: soil-moisture sensing devices, commercial irrigation scheduling services, or computer simulation models.

There is a significant positive association between farm size and use of the most water-management-intensive and water-conserving means to decide when to apply water (Table 3-5). The association is stronger in New Mexico ($\gamma = 0.60$) than in Arizona ($\gamma = 0.36$). The dominant methods to decide irrigation timing are observation of the condition of the crop and by the “feel of the soil.” Next in importance was calendar scheduling.

There was a negative association between having water delivered in turn and farm size. In New Mexico, 25 percent of small farms responded that water was delivered in turn, suggesting little discretion over when to apply water. Adoption rates of soil moisture testing or commercial services were relatively low for each farm size class. Both Arizona and New Mexico had positive and significant γ coefficient and Cochrane Armitage test statistics for soil moisture testing. In New Mexico, the γ for commercial scheduling was high (0.96) but adoption among even the very large farms was low (8 percent). In Arizona the γ for commercial scheduling was weakly negative (-0.08). While significant at the 5 percent level for the γ test, it was insignificant under the Cochrane-Armitage test.

Use of media reports is slight outside the very large farm size category and still low (6 percent for Arizona and 10 percent for New Mexico). Although a question was asked about use of computer simulation models, adoption is essentially non-existent in these two states.

Barriers to Improvements to Irrigation Systems and Practices

In the 1998 FRIS survey, producers were asked, “What were barriers to implementing improvements that might reduce energy and / or conserve water in your irrigation system?” In an earlier question, respondents were instructed to consider changes in equipment or management practices as improvements. Respondents were given a choice of barriers and instructed to mark all that applied to them.

Table 3-5: Method to determine time to apply irrigation water (AZ)

Arizona

Farm sizes	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	Other practices	Water-management-intensive and water-conserving
(Values are percentage yes responses)										
Small	63	5	7	7	0	7	28	0	0	7
Medium	88	30	0	1	0	3	25	0	3	0
Large	66	27	12	--	0	--	51	0	5	12
Very Large	91	50	14	8	6	5	30	1	5	20
Gamma	0.45	0.76	0.23	-0.08	1	-0.28	0.13	1	0.78	0.36
Gamma z	15.55	26.14	7.85	-2.36	34.45	-8.90	4.37	38.51	26.87	12.49
Cochran-Armitage -z	10.76	23.25	4.70	-0.06	9.57	-2.94	3.40	4.49	8.86	7.86
New Mexico										
Small	61	23	5	0.07	0.20	25	31	*	2	5
Medium	91	19	8	--	2	2	10	*	9	9
Large	93	39	8	3	--	--	13	*	6	15
Very Large	84	58	21	8	10	9	15	*	5	28
Gamma	0.66	0.34	0.48	0.96	0.90	-0.75	-0.51	*	0.55 *	0.60
Gamma z value	48.89	24.96	35.58	64.81	60.70	-50.27	-37.49	*	40.77	44.06
Cochran-Armitage -z	12.65	11.73	10.36	18.51	16.12	-10.81	-8.87	*	6.04	15.18

Significance level = 5% for | z | = 1.96; = 1% for | z | = 2.576; = 0.1% for | z | = 3.291; * insufficient data for tests

Response options were:

- Have not investigated improvements
- Risk of reduced yield or poorer quality crop yield from not meeting water needs
- Physical field/crop conditions limit system improvements
- Improvements will reduce costs, but not enough to cover the installation costs
- Cannot finance improvements, even if they reduce costs
- Landlords will not share in the cost of improvements
- Uncertainty about future availability of water
- Will not be farming this place long enough to justify new improvements.

Table 3-6 shows results for the first response “have not investigated improvements.” Of small farms in Arizona, 59 percent responded that they had not investigated improvements, while the response was 23 percent among small farms in Arizona. In both states there was a significant negative association between farm size and a yes (no investigation) response. The relationship was particularly strong in Arizona ($\gamma = 0.814$).

Table 3-6: Farms not investigating irrigation improvements

Farm size	Arizona	New Mexico
	percent responding yes	
Small	59	23
Medium	14	4
Large	10	23
Very Large	9	9
Gamma	-0.814	-0.396
Gamma z	-28.00	-29.19
Cochran-Armitage -z	-22.80	-5.85

Initial γ and Cochrane-Armitage tests also suggested that there was a positive association between nearly all of the barriers and farm size. This result runs counter to the vast bulk of literature which suggests that larger farms are more likely to adopt irrigation improvements. What accounts for the counter-intuitive result? One possibility is that farmers who responded that they had not investigated improvements did not mark any other barriers to adoption. This assumes that only farmers seeking to implement improvements would encounter the other barriers. There is no way of knowing if this is a reasonable assumption or not without looking at the original raw data files. Table 3-7, however, shows each farm size class' share of the total "have not investigated improvement" responses.

Table 3-7: Farm size class shares of total responses "have not investigated improvements" in irrigation

Farm Category	Arizona		New Mexico	
	Number of farms	%	Number of farms	%
Small	989	90.9	1216	94.1
Medium	31	2.8	11	0.9
Large	27	2.5	43	3.3
Very Large	41	3.8	22	1.7
Total	1088	100	1292	100

Small farms account for over 90 percent of the responses in each state. In Table 3-8 below, percentages, and hypothesis tests were carried out removing these observations from the total. Table 3-8, then, shows farms experiencing adoption barriers as a share of farms investigating improvements. The results still generally show that the likelihood of encountering barriers increases with farm size class.

Table 3-8: Barriers to Adopting Irrigation Improvements

Farm size	Risk of reduced yield or quality	Physical field or crop conditions	Installation costs > than benefits	Lack of financial ability	Lack of landlord cost sharing	Uncertainty about future water availability	Will not be farming in the future	Other reasons
Arizona								
(Values are percentage responses)								
Small	8	11	28	22	--	3	--	8
Medium	10	8	37	57	4	7	22	32
Large	15	17	50	52	13	19	0	12
Very Large	15	14	28	26	23	12	7	22
Gamma	0.25	0.14	0.06	0.14	0.63	0.42	0.38	0.31
Gamma z	8.51	4.72	2.20	4.84	17.66	14.54	13.28	10.80
Cochran Armitage -z	4.11	2.45	1.46	2.88	10.54	6.57	3.78	5.53
New Mexico								
Small	6	12	19	27	3	15	21	6
Medium	5	6	8	20	5	18	--	5
Large	26	16	28	34	16	17	4	7
Very Large	19	14	37	23	16	13	7	6
Gamma	0.46	-0.04	0.14	-0.06	0.61	0.01	-0.64	-0.01
Gamma z	33.72	-3.00	9.95	-4.76	45.22	1.16	-42.82	-0.68
Cochran Armitage -z	9.75	-0.39	5.44	-0.93	11.84	0.23	-8.34	-0.04

Significance level = 5% for | z | = 1.96; = 1% for | z | = 2.576; = 0.1% for | z | = 3.291;

The positive associations are weaker than in the case including the full sample, however. Economic constraints (installation costs outweighing benefits and lack of financing) are the dominant constraints. Interestingly, lack of landlord financing appears to be more of constraint for larger, than smaller farms. Also, more than 20 percent of Arizona's small farms and New Mexico's medium-sized farms responded that they did not expect to be farming long enough to make investments pay off. This figure was 7 percent in each state for the very large farm class. This may be more significant considering that these larger farms account for a relatively larger share of overall water use.

Farm Size and Water Use Distribution

Table 3-9. Total water applied (and percent distributions), by farm, for 1998 FRIS irrigated farms (units = 1,000 acre feet)

	Farm size class based on farm sales[1]									
	small		Medium		large		very large		All farm size classes	
State	Acre feet (1,000)	%	Acre feet (1,000)	%	Acre feet (1,000)	%	Acre feet (1,000)	%	Acre feet (1,000)	%
Arizona	183.2	4.4	284.9	6.9	491.0	11.9	3,158.6	76.7	4,117.7	100
New Mexico	444.3	25.7	207.8	12.0	250.5	14.5	827.4	47.8	1,729.9	100

Table 3-10. Total number of irrigated farms (and percent distributions), by farm size and State, for 1998 FRIS irrigated farms

	Farm size class based on farm sales[1]									
	small		medium		large		very large		All farm size classes	
State	Farms	%	Farms	%	Farms	%	Farms	%	Farms	%
Arizona	1,678	63.6	216	8.2	279	10.6	464	17.6	2,637	100
New Mexico	5,336	88.4	276	4.6	184	3.0	239	4.0	6,035	100

The very large farm class in Arizona accounts for less than 18 percent of the farms, but 76.7 percent of irrigation water applied. In New Mexico 12 percent of farms (medium, large, and very large) account for nearly 75 percent of irrigation water applied. Tables 3-9 and 3-10 also highlight the very different farm structures in Arizona and New Mexico. In New Mexico, over 88 percent of farms are in the small size category and they apply over a quarter of the water. In contrast there are many more very large farms in Arizona. In Arizona, small farms apply only 4.4 percent of the irrigation water.

Participation in Water Conservation Cost Share Programs

Federal, state, and local agriculture conservation programs provide cost-share payments to farmers to encourage adoption of farm-level conservation practices. The 1998 Farm & Ranch Irrigation Survey (FRIS) collected data on farm-level participation in cost-share programs, asking farmers whether in the previous 5 years (1994-98) they received irrigation-related cost-share payments for irrigation improvements from one or more of the following sources:

- USDA conservation cost-share programs [including the Environmental Quality Incentive Program (EQIP) and other earlier USDA cost-share programs]
- Non-USDA Federal cost-share programs [including those from the Environmental Protection Agency (EPA), the Bureau of Reclamation, or other programs]
- State programs and local water management or supply district programs
- Other cost-share programs.
- Any federal program
- Any program of any source

Table 3-11 Participation in water conservation cost share programs

Particulars	USDA cost-share payments	Non-USDA Federal programs	State/local programs	Other programs	Any Federal program	From any program source
Arizona						
(Values are percentage yes responses)						
Small	1	1	7	1	1	8
Medium	6	0	0	4	6	11
Large	12	4	5	6	12	18
Very Large	26	5	8	5	27	34
Gamma	0.82	0.68	-0.06	0.57	0.83	0.55
Gamma z value	28.26	23.51	-2.10	19.54	28.53	18.88
Cochran-Armitage -z	18.47	6.94	-0.02	6.54	19.03	13.96
New Mexico						
Small	6	5	4	3	7	8
Medium	15	5	5	5	15	15
Large	14	6	6	3	16	16
Very Large	22	5	9	3	24	30
Gamma	0.49	0.08	0.28	0.04	0.49	0.48
Gamma z value	36.17	6.16	20.58	3.25	36.09	35.15
Cochran-Armitage -z	10.38	0.81	4.01	0.26	11.03	11.74

Significance level = 5% for | z | = 1.96; = 1% for | z | = 2.576; = 0.1% for | z | = 3.291;

Among very large farms, 30 percent of New Mexico farms and 34 percent of Arizona farms participated in some form of cost-share program (Table 3-11, last column). Participation rates for small farms were lower, 8 percent in both states. There is a significant positive association between cost-share program participation and farm size. In Arizona, the positive association is greater than in New Mexico, except for state and local programs. Here, there is a weak negative association γ = -0.06, while the trend coefficient is insignificant using the Cochrane-Armitage test. The positive association is relatively strong for USDA participation in Arizona γ = 0.82. Only 1 percent of Arizona small farms reported having USDA contracts, while this number was 6 percent for New Mexico. In New Mexico, there was a significant, but weaker association between farm size and USDA participation (γ = 0.49).

Table 3-12: Farms receiving cost-share payments from EQIP (or other USDA programs) and from state programs or local water management or supply districts (1994-98) for irrigation or drainage improvements.

<table>
<tr><td colspan="11">Farms receiving EQIP payments</td></tr>
<tr><td></td><td colspan="2">small</td><td colspan="2">medium</td><td colspan="2">large</td><td colspan="2">very large</td><td colspan="2">All farm size classes</td></tr>
<tr><td>State</td><td>Farms</td><td>%</td><td>Farms</td><td>%</td><td>Farms</td><td>%</td><td>Farms</td><td>%</td><td>Farms</td><td>%</td></tr>
<tr><td>Arizona</td><td>17</td><td>9.3</td><td>14</td><td>7.7</td><td>33</td><td>18</td><td>119</td><td>65</td><td>183</td><td>100</td></tr>
<tr><td>New Mexico</td><td>333</td><td>73.7</td><td>42</td><td>9.3</td><td>25</td><td>5.5</td><td>52</td><td>11.5</td><td>452</td><td>100</td></tr>
<tr><td colspan="11">Farms receiving payments from state and local programs</td></tr>
<tr><td></td><td colspan="2">small</td><td colspan="2">medium</td><td colspan="2">large</td><td colspan="2">very large</td><td colspan="2">All farm size classes</td></tr>
<tr><td>Arizona</td><td>120</td><td>69.8</td><td>0</td><td>0</td><td>15</td><td>8.7</td><td>37</td><td>21.5</td><td>172</td><td>100</td></tr>
<tr><td>New Mexico</td><td>206</td><td>81.4</td><td>15</td><td>5.9</td><td>11</td><td>4.3</td><td>21</td><td>8.3</td><td>253</td><td>100</td></tr>
</table>

Table 3-12 provides information about the targeting of EQIP (USDA) and state / local cost-share programs. In Arizona, EQIP payments are targeted more toward larger farms and less than 10 percent of small farms reported receiving USDA payments. In contrast, in New Mexico, nearly three-quarters of small farms reported receiving some USDA cost-share payments. In both Arizona and New Mexico, small farms account for the great majority of farms receiving state/local cost-share payments (Table 3-12). Small farms in New Mexico accounted for over 81 percent of farms receiving state / local payments, while in Arizona, small farms accounted for nearly 70 percent of farms receiving state / local payments.

Discussion

The 1998 FRIS survey results show that irrigators rely on diverse sources of information about water management. Of all the sources of information listed in Table 3-4, there was no single source that was relied upon by more than half of any farm size group. This means that for the purpose of outreach and technology transfer, there is no one single source of information that will reach all irrigators. The most common sources of information were extension agents / university specialists and neighboring farmers. This suggests that the traditional extension-based demonstration farm approach to technology transfer will still be a relatively effective, compared to other sources. A significant share of irrigators, however, does not rely on these sources of information.

The relative reliance on different sources of information varies systematically with farm size. Larger farmers tend to rely more on irrigation equipment suppliers and government specialists. Small irrigators rely more on their irrigation districts. Smaller irrigators are also more likely to have the timing of irrigation decided by the district, with deliveries provided “in turn” (Table 3-5). For small irrigators, then, targeting outreach directly at irrigation district staff may be a cost-effective approach to extension delivery.

The adoption of what Leib et al. (2002) call scientific irrigation scheduling (SIS) (soil moisture testing, computer models, or commercial irrigation scheduling services) and what ERS calls “most water-management-intensive and water-conserving” is limited in both states. Consistent with Leib et al.’s results for Washington state, the “feel of the soil” method was among the most commonly used methods to schedule irrigation and there was a positive association between farm size and adoption of SIS methods. SIS methods were used by only 20 of very large farms in Arizona and 28 of very large farms in New Mexico (Table 3-5, last column). Adoption rates are even lower for smaller farm size classes. Use of media reports to determine crop irrigation needs was almost wholly confined to the very large farm class. Adoption rates per irrigated acre or per acre-foot of water used will be higher, however, because the very large farm class accounts for large shares of water use in both states.

Small farms were much less likely to investigate irrigation improvements with 59 percent of Arizona small farms and 23 percent of New Mexico small farms responding that they had not investigated improvements in previous years. By comparison, the response rate of the very large farm class in each state was 9 percent. In New Mexico, however, 23 percent of the large farm class also responded that they had not investigated improvements. Small farms in both states, however, accounted for over 90 percent of farms not investigating improvements. The γ and Cochrane-Armitage tests suggest a strong positive association between farm size and investigation of improvements.

Overall, the most prevalent barriers cited by irrigators were financial. Initially, analysis suggested a positive association between farm size and barriers to adoption. When the data was adjusted to be the ratio of farms in a size class experiencing a barrier to total farms investigating improvements (as opposed to total farms) the positive association was reversed or weakened, but still remained for some barriers. In particular, it remained for lack of landlord cost-sharing and for concern about impacts on crop quality. Recall, that the farm size classes are in terms of sales. There may be some effect of high value crop production that accounts for this relationship.

The results also show a positive relationship between EQIP (and other USDA program) participation and farm size. While there was a positive association between EQIP participation and farm size class in both states, the association was much stronger in Arizona. States have latitude in administration of EQIP programs and Arizona appears to be targeting larger irrigators. The very large farm class accounts for 65 percent of farms receiving EQIP payments and 77 percent of irrigation water applied. In contrast, the small farm class in New Mexico accounts for 74 percent of EQIP payments, but less than 26 percent of irrigation water applied. Although participation rates increase with farm size in New Mexico, small farms account for a large share of total farms, over 88 percent. So, they account for a large share of total contracts.

In both states, state/local programs target small farms, although these programs reach a small share of irrigators. In Arizona, only 7 percent of small irrigators received state / local payments. In New Mexico, this figure was 4 percent. However, Arizona small farms accounted for nearly 70 percent of farms receiving this assistance, even though they account for 4.4 percent of water use. In New Mexico, small farms accounted for 81 percent of farms receiving state / local cost-share payments, but less than 26 percent of water use.

These results have implications for program targeting. Schaible (2004 b) has argued that water conservation program efficiency could be increased by targeting those farms that account for relatively more water use. It appears that the administration of EQIP in Arizona does just this. In New Mexico, there a large number of small farms that still account for a large share of EQIP contracts. In both states, state / local programs, though very limited, appear to be targeting irrigators that account for a small share of overall irrigation water use.

CHAPTER 4

Factors Affecting Adoption of Sprinkler Irrigation Systems

Sprinkler irrigation systems use pressure to distribute water. The pressure to distribute water involves pumping, which requires energy. These systems are used extensively for supplemental irrigation and for specialty crop irrigation. There are a number of advantages to using sprinkler irrigation systems:

- They apply water more efficiently to crops and can be a water-conserving alternative to gravity irrigation systems.
- They can be operated on moderately sloping or rolling terrain unsuited to gravity irrigation systems.
- Sprinklers are well suited to coarser soils with higher water infiltration.
- Irrigation with sprinklers requires less labor than gravity systems.

Some disadvantages for using sprinkler irrigation systems are that:

- Capital costs for sprinkler irrigation systems are higher than for gravity irrigation systems.
- Sprinkler systems require more energy than gravity systems.

Review of Literature

A brief review of the literature on various factors affecting the adoption of sprinkler irrigation systems is stated below:

Temperature: Mendelsohn and Dinar (2003) concluded that sprinklers are likely to be adopted in wet, cool climates. At high temperatures these irrigation systems are not likely to be adopted because of high evaporation losses. Caswell et al. (2001) concluded that low average rainfall and high temperatures increases the probability of adoption of both sprinkler and gravity systems. Nieswiadomy (1998) also concluded that the likelihood of adoption of modern irrigation technologies is apt to increase in regions with higher temperatures.

Rainfall: Caswell et al. (2001) concluded that low average rainfall increases the adoption of both sprinkler and gravity systems. Negri and Brooks (1990) concluded that the probability of adopting sprinkler relative to gravity technology varies positively with total rainfall because sprinkling permits greater control over the quantity of water applied.

Frost: Boggess et al. (1993) and Negri and Brooks (1990) found that sprinkler irrigation is used effectively for frost protection and therefore is more likely to be adopted in regions with frost problems. Negri and Brooks also found that adoption of sprinkler irrigation systems varies inversely with growing degree days.

Wind: Caswell et al. (2001) confirmed that fields with higher wind erosion levels are more likely to be irrigated with sprinkler systems and adoption of improved irrigation technology like sprinklers helps in conserving water.

Water source: Negri and Brooks (1990) found that adoption of sprinkler irrigation systems increases with a decrease in access to surface water relative to groundwater. Caswell and Zilberman (1985) concluded that farmers who apply ground water are more likely to adopt sprinkler irrigation systems. In contrast, in an analysis of county-level data from the whole United States, Mendelsohn and Dinar (2003) found that relative reliance on surface water was positively related to use of sprinklers.

Soil and land characteristics: Caswell et al. (2001) found that field slope had no effect on the adoption of sprinkler irrigation systems. Center pivot or sprinkler systems were more likely to be used on soils with higher leaching potential. Negri and Brooks (1990) found that sprinkler irrigation systems are land quality augmenting and soil slope, sandy soils increase the adoption of sprinkler irrigation systems. Nieswiadomy (1988) found that the likelihood of adoption of modern irrigation technologies is apt to increase as soil slope increases and water holding capacity declines.

Water costs: Negri and Brooks (1990) Nieswiadomy (1988), Caswell and Zilberman (1985) found that the probability of water saving irrigation technology like sprinkler irrigation systems increases with the cost of water.

Wages: Mendelsohn and Dinar (2003) concluded that adoption of sprinkler irrigation systems increases with higher wage rates in January but lower wage rates in April. Skilled permanent irrigation experts increased the likelihood of adoption of modern irrigation and improved farm performance. Negri and Brooks (1990) found that higher wages were associated with greater adoption of sprinkler irrigation systems. Nieswiadomy (1988) indicated that the likelihood of adoption of modern irrigation technologies is apt to increase as the prices of labor increases.

Farm size: Caswell et al. (2001) in their study found that the number of acres operated did not have an effect on the use of sprinkler systems. Clearfield and Osgood (1986) surveying a number of studies found that larger the farm size and the more income produced by the farm enterprise, the greater the use of conservation practices, generally. Negri and Brooks (1990) found that small farms are more likely to adopt sprinkler irrigation systems. They argued that on small farms with gravity distribution systems, the water loss through conveyance ditches can constitute a large share of total water losses which makes small farms more likely candidates for sprinkler systems.

The Model Explaining Adoption Proportions

The dependent variable for this analysis is the proportion of total irrigated acres that use sprinkler irrigation. Data for 17 Western states are available from special tabulations of the 1998 Farm and Ranch Irrigation Survey (USDA, NASS, 1998) developed for USDA's Economic Research Service. This special tabulation reports data by state and four farm size classes, with size measured in terms of sales (the same farm size classes as defined in Chapter 3). The adoption proportions are P_{ij}, where i is the number of states (i = 1, . . . 17) and j is the number of farm size classes (small =1; medium = 2; large = 3; very large = 4).

The data can be listed as follows.

P_{i1} = fraction of irrigated acreage using sprinkler irrigation on small farms in state i.

P_{i2} = fraction of irrigated acreage using sprinkler irrigation on medium farms in state i.

P_{i3} = fraction of irrigated acreage using sprinkler irrigation on large farms in state i.

P_{i4} = fraction of irrigated acreage using sprinkler irrigation on very large farms in state i.

There are a cross section of 17 states and four farm size classes within each state for a total of 68 observations. The states in the sample are Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington and Wyoming.

Following previous work on irrigation adoption using proportions data (Caswell and Zilberman; Schaible, et al.; Mendelsohn and Dinar), the regression equation explaining adoption is specified as a logistic function:

$$\ln(P_{ij}/(1-P_{ij})) = \alpha_0 + \alpha_1\text{Small} + \alpha_2\text{Medium} + \alpha_3\text{Large} + \boldsymbol{\beta}'\mathbf{X}_{ij} + u_{ij}$$

where

Small = 1 for small farms; = 0 otherwise

Medium = 1 for medium farms; = 0 otherwise

Large = 1 for large farms; = 0 otherwise

$\mathbf{X}_{ij}$ = a vector of other explanatory variables (discussed below)

u_{ij} = a stochastic error term.

A constant term is included, so one dummy (for very large farms) is omitted to prevent perfect collinearity. Coefficients for the other dummy variables can be interpreted as the impact of difference from the default (very large farm) class.

Negri and Brooks found a negative relationship between farm size (measured as irrigated acreage) and sprinkler adoption, while Caswell and Zilberman found evidence of higher adoption rates among farms in Kern County (where farms were larger than comparison counties) were higher. Our farm size classes are in terms of gross sales. The size class variables, then, may also pick up effects of producers growing higher value crops. Caswell and Zilberman and Schaible et al. both found evidence of greater adoption for relatively higher valued crops.

Explanatory Variables

APC: Average pumping costs ($ per acre): Pressurized irrigation systems use a pump for delivering water. Irrigation pumping costs vary by energy source used to power the pump. Source: Data sets – Western Irrigated Agriculture – table 4.1 b (Schaible 2004a) http://ers.usda.gov/data/westernirrigation/Tables/4-1b.xls. (Schaible 2004a)

SW: Percent of surface water to total irrigation water from all sources

Source: Data sets – Western Irrigated Agriculture – table 1.8 and 1.10 (Schaible 2004a)

http://ers.usda.gov/data/westernirrigation/Tables/1-8.xls

http://ers.usda.gov/data/westernirrigation/Tables/1-10.xls (Schaible 2004a)

Temp : Annual mean temperature in ^{0}F. Average in state i weighted by harvested acres.

Tempsq : Temp variable squared.

Below32 : Number of months mean monthly temperature is < 32 degrees ^{0}F

Average in state i weighted by harvested acres.

For the three temperature variables, temperature weighted by harvested cropland has been used. The weighting approach is described in Teigen and Singer (1992). The average daily temperature is the average of the daily maximum and daily minimum temperatures. The average of the maximum and minimum of the month's daily average temperature is the station's monthly average temperature. The arithmetic average of these average temperatures over all the stations in a climate division provides the average temperature for the division. The estimate of weather over the harvested cropland is derived when the weights are the harvested cropland in the climatic divisions. Harvested cropland varies from year to year in response to commodity prices and to the provisions of current federal farm programs. The weights used in this report were derived from the 1974 and 1978 agricultural censuses. For each division, the harvested cropland weight is the simple average of the estimates derived from the 1974 and 1978 censuses.

AEFL: Average annual sheet and rill erosion on nonfederal land (tons/per acre/year) The universal soil loss equation (USLE) is used to estimate the average annual soil loss from sheet and rill erosion. The equation is: A = RKLSCP, where A is the computed soil loss per unit area, R is a rainfall factor, K is a soil erodibility factor, L is a slope length factor, S is a slope-steepness factor, C is a cover and management factor, and P is a conservation practice factor. Source: National Resources Conservation Service (NRCS) (USDA). http://www.nrcs.usda.gov/technical/NRI/1997/summary_report/table10.html.

JANWage and APRWage: January farm labor wages and April farm labor wages in dollars. These are the wages per hour for hired agricultural field laborers. Wage rates are reported on a multi-state regional basis. Source: USDA, NASS, *Agricultural Statistics* 2003, Table 9.19. http://www.nass.usda.gov/Publications/Ag_Statistics/agr03/03_ch9.pdf.

Descriptive statistics for the variables are presented in Table 4-1. Adoption rates for sprinkler irrigation range across state-farm size pairs from 2 percent to 88 percent. There are also wide ranges between minimum and maximum values for water pumping costs, the soil erosion, relative reliance on surface water, and number of months with mean temperature below 32 degrees F.

Table 4-1. Descriptive Statistics

Variable Name	Variable Description	Mean	Min	Max
P_{ij}	Proportion of sprinkler area to the total irrigated area	0.51	0.02	0.88
APC	Average pumping costs	34.34	11.00	147.12
SW	Proportion of surface water to total irrigation water from all sources	0.59	0.007	0.99
Temp	Mean Annual temperature	51.23	40.28	68.42
AEFL	Average annual sheet and rill erosion on non federal land	1.99	0.20	4.70
Below32	Number of months the mean monthly temperature < 32 degrees F	2.12	0.00	5.00
JANWage	January farm wages for hired labor	7.23	6.53	8.34
APRWage	April farm wages for hired labor	6.85	6.2	7.55

Results

The estimated regression coefficients of the independent variables along with the standard errors are presented in table 4-2. The model was estimated using ordinary least squares methods.

The coefficients for small, medium, and large farms are negative and statistically significant (Table 4-2). This indicates that acres irrigated by these farms are less likely to be irrigated with sprinkler systems than very large farms.

The coefficient for average pumping costs is positive and significant indicating that the higher the pumping costs, the greater is the proportion of acres using sprinkler irrigation systems. Greater reliance on surface water is negatively related to the proportion of acres using sprinkler irrigation systems. This result is in consistent with the findings of Negri and Brooks (1990). The coefficient for mean annual temperature is positive and significant, while the coefficient on the squared term is negative. Within the sample range of temperatures (40.28 to 68.42 degrees F), this implies that increased temperature causes ln(P/1 – P) to increase at a decreasing rate.

The coefficient for the variable number of months mean temperature less than 32 degrees Fahrenheit was found to be positive and significant. This variable is used to account for frost. The positive coefficient implies (consistent with Negri and Brooks) that sprinkler irrigation is more likely to be adopted in regions with frost problems.

The coefficient on average annual sheet and rill erosion on nonfederal land is

Table 4.2: Factors affecting the adoption of sprinkler irrigation, OLS results

Dependent Variable: ln [$(P_{ij} / 1 - P_{ij})$]

Adjusted R – squared: 0.84

Number of Observations: 68

Label	Parameter Coefficient	Standard Error	P Value
Intercept	-23.74	3.422	<0.0001
Small	-0.72	0.188	0.0003
Medium	-0.45	0.184	0.0183
Large	-0.49	0.183	0.01
APC	0.01	0.004	0.0241
SW	-2.37	0.272	<0.0001
Temp	0.91	0.128	<0.0001
TempSQ	-0.008	0.001	<0.0001
Below32	0.27	0.058	<0.0001
AEFL	0.62	0.068	<0.0001
JANWage	0.36	0.228	0.1183
APRWage	-0.44	0.313	0.1598

positive and significant indicating that in areas with high erosion, sprinkler irrigation systems are more likely to be adopted. This result is in consistent with the findings of Caswell et al. (2001). Because sheet and rill erosion is more likely on areas with steeper slopes and greater rainfall, this variable may be picking up the effects of those variables. Both Negri and Brooks and of Mendelsohn and Dinar found a positive association between soil slope and sprinkler adoption and Mendelsohn and Dinar between rainfall and sprinkler adoption.

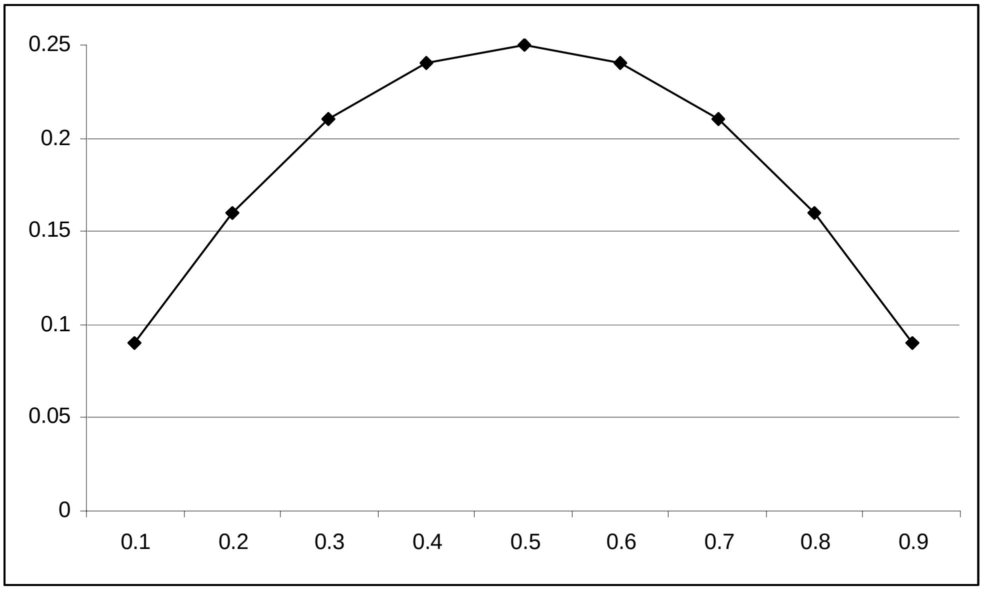
Similar to Mendelsohn and Dinar's findings, the coefficient for January wages is positive and April wages is negative. Because sprinkler systems tend to be labor-savings one would expect that higher wages would encourage sprinkler adoption. Negri and Brooks, using annual wage rates find a positive relationship. Dinar, Campbell and Zilberman (1992) also find a positive relationship. Mendelsohn and Dinar provide no explanation for the negative relationship between April wages and sprinkler adoption. The wage coefficients are not significant (at the 10 percent level) however.

Table 4-3 report the marginal effect of the explanatory variables on the proportion of acres using sprinkler irrigation. The marginal effects are calculated at the sample means for each of the farm size classes separately. One result, which was surprising at first, but that can be explained is the small difference in marginal effects across farm size classes. Remember that the coefficient for the small farm size class dummy variable was statistically significant and negative. So, one might expect marginal effects for smaller farms to be lower.

Table 4-3: Marginal effects of factors affecting sprinkler irrigation systems				
	Marginal Effects			
	Small	Medium	Large	Very Large
APC	0.002	0.002	0.002	0.002
SW	-0.562	-0.590	-0.592	-0.567
TEMP	0.215	0.226	0.227	0.217
BELOW32	0.064	0.067	0.067	0.064
AEFL	0.146	0.154	0.154	0.147
JANWage	0.085	0.089	0.090	0.086
APRWage	-0.105	-0.111	-0.111	-0.106

The marginal effects of a variable X with a coefficient β for a logistic function is $\partial P_e/\partial X = \beta\, P_e(1 - P_e)$ where P_e are the estimated proportions from the regression equation (Greene 1996). When evaluated at sub-sample means, the P_e terms for each farm size class range from 0.4 to 0.6. Figure 4-1 shows $P_e(1 - P_e)$ as a function of P_e.

Figure 4-1. (1 – P) P as a function of P (where 0 < P < 1 is proportion of adoption)



The predicted proportions (evaluated at sub-sample means across the farm size range between 0.237 and 0.25. From this graph, we can see that for the values in this range, the $P_e (1 - P_e)$ curve is relatively flat. Because of this, differences in marginal effects ($\partial P_e/\partial X = \beta P_e (1 - P_e)$) will be small across farm size classes.

Conclusions

Using a simple model dividing irrigators into state-farm size class pairs, a simple OLS regression explains differences in the extent of adoption of sprinkler irrigation (relative to gravity irrigation) across 17 western states. The model explains over 84 percent of the variation in the log proportion of adopting acres to non-adopting acres. The proportion of acres irrigated with sprinkler irrigation was greater for very large farms (with farm size measured in terms of sales) than for small, medium or large farm size classes. Adoption was also positively influenced by the extent of sheet and rill erosion, which may proxy for steeper slopes and greater rainfall. Consistent with Negri and Brooks, greater reliance on surface water reduced reliance on sprinkler irrigation. The extent of sprinkler adoption was also positively related to number of months with mean temperatures below freezing.

These results suggest that a relatively small number of economic and environmental variables explain a considerable portion of sprinkler adoption. It also illustrates how the special tabulations of irrigation practices by farm size class developed by USDA's Economic Research Service can by used for multivariate regression analysis. The results also demonstrate the importance of farm size differences in irrigator behavior. Chapter 3 examined farm size irrigation relationships in a univariate setting. This chapter illustrates how farm size matters even controlling for other variables.

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