THE WATER USE AND CLIMATE EFFECTS ON FARM PROFITABILITY IN COLORADO RIVER BASIN

by

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STATEMENT BY AUTHOR

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ABSTRACT

The Colorado River is the lifeblood of the southwestern United States. The imbalance between water supply and demand in this basin has been increasing and conditions are projected to worsen with climate change and population growth. Because agriculture is a major user of groundwater and surface water in this region, federal and state agencies suggest that substantial cuts in agricultural water use will be required to re-balance water supply and demand. Such cutbacks, though, impose opportunity costs in the form of lost agricultural production and farm income. This study considers the regional distribution of net returns to irrigated agriculture in Colorado Basin states to address where such opportunity costs will be low and high. In some counties, net farm returns per acre of irrigated land or per acre-feet of water applied are quite high, while in others areas are low. The study also examines which factors determine why farm profitability is low or high across counties. The relationship between net farm income and a set of weather, climate variability, water resource availability and farm characteristic variables for the seven Colorado Basin states is examined using county-level data from 2005 and 2010. Regression results indicate that county level farm income per irrigated acre and per acre foot of water applied are significantly influenced by temperature, precipitation, and reliance on groundwater relative to surface water. A simple rationing model is applied to examine potential costs of large reductions in water use that might occur under land fallowing programs. If fallowing were concentrated in areas with the lowest gross revenues per acre foot of water, even substantial reductions in water use would have only a minimal effect on the value of regional production.

The water use and climate effects on farm profitability in Colorado River basin

1 Introduction

1.1 Colorado River basin water crisis

The Colorado River is the lifeblood of the southwestern United States. Stretching from the highest peaks of the Rocky Mountains to the Gulf of California, it travels over 1,400 miles across a watershed that includes seven states (Arizona, California, Colorado, New Mexico, Nevada, Utah, and Wyoming) within the United States and two states in northern Mexico, as shown in the map in Figure 1.1 [*Science et al.*, 2007].

The Colorado River and its tributaries provide water to nearly 40 million people for municipal use, supply water to irrigate nearly 5.5 million acres of land, and is the lifeblood for at least 22 federally recognized tribes, seven National Wildlife Refuges, four National Recreation Areas, and 11 National Parks. Hydropower facilities along the Colorado River provide more than 4,200 megawatts of electrical generating capacity, helping to meet the power needs of the West and offset the use of fossil fuels [*Bureau of Reclamation*, 2012].

For the past fifteen years, many parts of the American West have experienced relentless drought. Figure 1.2 presents a map of U.S. drought conditions as of August 30, 2016. The plains of Southeastern Colorado are experiencing Dust Bowl conditions. In New Mexico, the Rio Grande is running so low that local residents refer to it as the Rio Sand. The drought in Texas has caused more than $25 billion in economic damage [*Culp et al.*, 2015]. The Bureau of Reclamation projected that the level of Lake Mead—the massive water reservoir formed behind Hoover Dam, could decline so that the hydropower production at Hoover Dam would be jeopardized. It would also affect the ability of the Southern Nevada Water Authority (SNWA) to divert water from the reservoir to supply the Las Vegas metropolitan area. To address this risk, SNWA is currently undertaking one of the most complex engineering projects in the world, installing a new $1 billion “bathtub drain” intake at the bottom of Lake Mead to supplement two other intakes that could potentially be stranded above the lowered level of the lake [*Culp et al.*, 2015].

Figure 1. 1 Colorado River Basin Map.

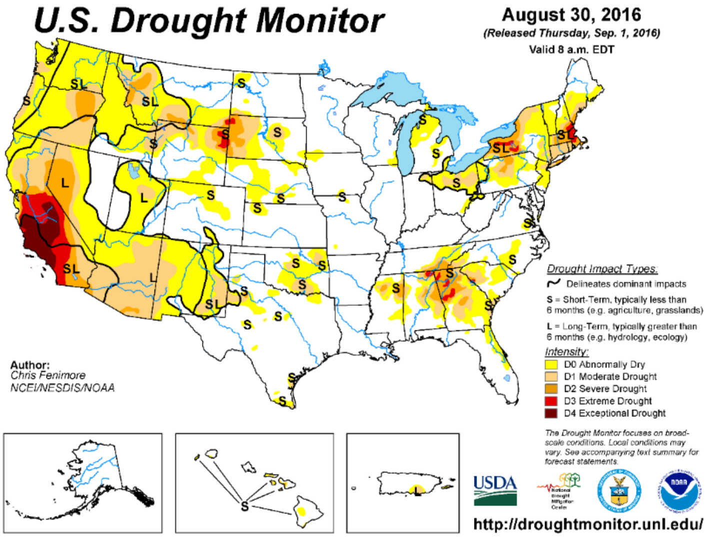

Figure 1. 2 U.S. Drought conditions on August 30, 2016.

(Source: The National Drought Mitigation Center 2016.)

1.2 Imbalance between supply and demand

In December 2012, the Bureau of Reclamation released a comprehensive analysis of water supply and demand in the Colorado River Basin. As shown in Figure 1.3, the study estimated the average demand for the water in the Colorado River Basin has exceeded the average available supply every year since 2003. In looking ahead, the study concluded that the long-term projected imbalance in future supply and demand in the basin would continue to increase, and reach 3.2 million acre-feet per year by 2060 on average. That is an imbalance equivalent to approximately 20 percent of current Basin-wide demands.[*Bureau of Reclamation*, 2012].

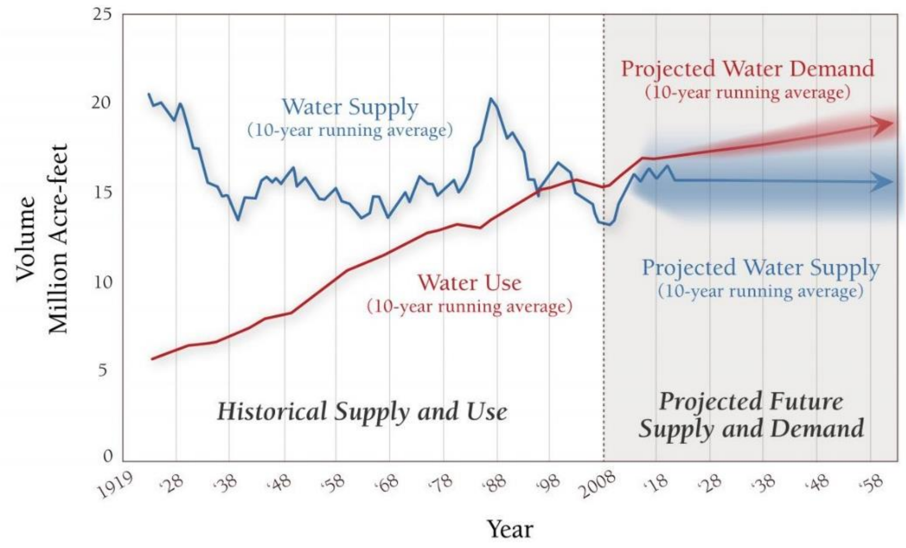

Figure 1. 3 Historical Supply and Use and Projected Future Colorado River Basin Water Supply and Demand.

(Source: Colorado River Basin Water Supply and Demand Study Executive Summary [*Bureau of Reclamation*, 2012].)

1.3 Western agriculture and water

Agriculture is a major user of subsurface and surface water in the United States, accounting for approximately 80 percent of the Nation's consumptive water use and over 90 percent in many Western States [*Sunding et al.*, 2016].

Water resources in the region that are already over-allocated face increasing competition from growing urban development, aesthetics and restoration, and environmental demands. However, agricultural water use is also affected by global climate change [*Fort*, 2002]. Climate change is likely to increase water demand while shrinking water supplies. In the western part of the United States, precipitation and agricultural water demands occur at different time intervals, i.e., less water is available during the summer months when demand is highest. This disparity between water availability and agricultural need is one of the most significant threats to western agricultural success [*USOTA*, 1983].

1.4 Study Region

The Colorado River rises in the mountains of Colorado and flows through Colorado, Utah, and Arizona and along the Arizona-Nevada and Arizona-California boundaries and Arizona-Mexico boundaries. The river and its tributaries drain portions of seven States: Wyoming, Colorado, Utah, New Mexico, Arizona, California and Nevada, or a vast area of approximately 242,000 square miles, about one-twelfth the area of the continental United States, excluding the States of Alaska and Hawaii. Most of the region is so arid that the viability of numerous communities in it is largely dependent upon the controlled and managed use of the Colorado River System and the availability of its water to make it productive and inhabitable. The upper portion is one of high elevations, narrow valleys, and a short growing season. The lower portion has lower elevations, wide basins and deserts, and a long growing season.

Total precipitation in the mountains reaches 1,000 to 1,500 mm per year. However, most of its course crosses the semi-arid Colorado Plateau and desert, where average annual precipitation may be as low as 60 mm [Mueller and Moody, 1984]. Extremes of temperature in the Colorado River Basin range from -50 to 130 degrees Fahrenheit. The northern portion of the Colorado River Basin is characterized by short, warm summers and long, cold winters; and many mountain areas are blanketed by deep snow all winter. Much of the area consists of high basins or valleys with cold winters and hot, dry summers. The southern desert portion of the Colorado River Basin has long, hot summers, practically continuous sunshine, and almost complete absence of freezing temperatures [*Interior,* 2003].

Most of the agricultural land in the area and major cities including Denver, Los Angeles, Phoenix and San Diego, depended on the Colorado River or its tributaries for their water supply. Ten major storage dams including the Glen Canyon Dam in the Upper Basin and the Hoover Dam in the Lower Basin have been built on the river to regulate its flow. However, construction of these reservoirs has caused environmental impacts such as sediment trapping, increased evaporation, salt concentration, thermal stratification of water in the reservoirs, and changes in aquatic species [*Ocean et al.*, 2018].

1.5 Purpose of research

Water is a critical input to agricultural production and inextricably linked to farm income. Specifically, this study seeks to explain how access to water and climate influences net agricultural producer income at the county level. I will provide an econometric analysis of panel data from seven western states for the year 2005 and 2010. The water supply in the future is becoming more and more dependent on allocation rights, conservation methods and improved efficiency.

The economic research question being addressed is: How do several independent factors, including crop water withdrawals, weather and climate factors, affect the farm net income of counties among seven states in the western United States? How might water supply reductions impact farm net income directly and how might one measure that impact? The specific objectives of this research project are as follows. 1) Determine the relationship between farm net income and the quantity of crop water usage that can be used for future water reallocation. 2) Determine the relationship between farm net income and precipitation and temperature. Ordinary least squares regression analysis will be used to simulate the relationship. 3) Evaluate the economic impact when facing water supply. The Rationing Model will be used to measure immediate impacts from water supply reductions.

The following chapters will include: Chapter 2, past research of the two areas examined in this Dissertation. Chapter 3, methods and data used in the regression analysis of the farm net income. Chapter 4, statistical results of the regression, and discussion from the analysis and simulation. And Chapter 5, conclusion and recommendations for further research.

2 Literature review

In this section, I will review the previous studies about factors impacting farm profit, discuss where this study fits in among previous work, and finally, present our study's economic theory to help motivating the estimated model that could be used in next chapter. I will also compare modeling approaches to measuring the economic effect of water shortage.

2.1 Factors affecting farm profitability

2.1.1 Determining factors

Agriculture is an important income source for farmers. It might be the only economic means to meet most farmers' financial needs. Sometimes it is an additional financial method of improving their quality of life. Therefore, farm profitability has a critical implication for farm survival, food security, and farmer welfare.

United States Department of Agriculture (USDA) Economic Research Service predicted that net farm income, a broad measure of profits, is going to decrease by $4.3 billion (6.7 percent) in 2018 from $59.5 billion in 2017, which is the lowest net farm income level in nominal dollar terms since 2006 [*USDA*, 2018]. Failure to sustain farm profit will drive more farmers out of agriculture.

Many factors have been found to influence farm profitability. Those factors can be grouped into four categories according to their similarity and their description: farmer and farm household characteristics, farm and biophysical characteristics, farm management and financial characteristics, and exogenous factors (such as weather) [*Tey and Brindal*, 2015]. Farmer and farm household characteristics measure the management capacity of farmers, such as education level and age [*Prokopy et al.*, 2008]. Farmers with high education levels may more easily acquire knowledge and new technology, and are more responsive to risk taking and change [*Masuku and Xaba*, 2013]. However, farmers' age is a complex factor related to farm profit. On the one hand, with increased age, farmers accumulate experience over time. On the other hand, aging farmers might have less motivation to strive for efficiency because most of them tend to value other life aspects more than monetary reward [*Tey and Brindal*, 2015].

Farm and biophysical characteristics refer to the feature of farm land, e.g., farm size, region, typology, soil fertility, and livestock holding. Farm management and financial characteristics describe how effectively a farm business is run, such as access to credit, sales price and technology improvement. Those factors are significantly and positively related to farm economic performance. In addition, farming is also associated with many exogenous factors, like crop insurance coverage and participation of training programs [*Tey and Brindal*, 2015]. Even through few past studies talked about the climate change and weather factors, those are very important factors correlated with the farm profitability. I will examine those effects in this study.

2.1.2 Farmers' profitability measurement

In the previous studies, researchers usually used four indexes to measure the farmers' profitability: accounting profit, net farm income, net farm income per farm or herd size, and rate of return on assets.

1. Accounting profit is the monetary costs a farm pays out and the revenue the farm receives. It is the bookkeeping profit, and it is higher than economic profit. Accounting profit is the difference between total monetary revenue and total costs.

2. Net farm income, in United States agricultural policy, refers to the return (both monetary and non-monetary) to farm operators for their labor, management

and capital, after all production expenses have been paid (i.e., gross farm income minus production expenses). It includes net income from farm production as well as net income attributed to the rental value of farm dwellings, the value of commodities consumed on the farm, depreciation, and inventory changes [*Bruner et al.*, 2005].

3. Net farm income per farm or herd size measures the average profit, which is the net farm income divided by the number of hectares or head of livestock. This index can compare the financial performance across different farm sizes [*Gloy et al.*, 2002].

4. Return on assets (ROA) is a financial ratio that shows the percentage of profit that a farm earns in relation to its overall resources. It is commonly defined as the net farm income adding interest expense and deducting unpaid labor and management expenses, and the capital return is then divided by the total assets [*Dartt et al.*, 1999].

2.1.3 Regression method

In general, Ordinary least squares, weighted least squares and structural equation models [*Ford and Shonkwiler,* 1994] have been used to identify the underlying determinants of farm profitability. Haden and Johnson, Gloy et al., and Jackson- Smith. used OLS regression to examine the impact on return on assets [*Haden and Johnson*, 1989] [*Gloy et al.*, 2002] [*Jackson-Smith et al.*, 2004]. Mishra et al. estimated the factors influencing the net farm income on limited resource farms by using weighted least squares (WLS) methods [*Mishra et al.*, 1999]. Mohammad also compared WLS and ordinary least squares (OLS) methods in terms of consistency and goodness of fit. The WLS method produced efficient and consistent results, whereas OLS regression was affected by the heteroscedasticity

[*Safa*, 2005].

2.2 Model approach to estimate economic effects of water reduction

In order to measure the economic effects of water cutbacks, two economic models are used in the past studies. The models described in this section are rationing model and U.S. Agricultural Resources Model (USARM).

The rationing model measures immediate impacts from water supply reductions. The only way to adapt to water cutback is to fallow land and cease production of the crops with the lowest marginal value of applied water [*Frisvold and Konyar*, 2012]. In fact, when water supply decreases, there are several possible responses from farmers. However, the rationing model approach places a number of assumptions that farmers do not consider crop rotation programs, do not adopt new technologies, and assumes that groundwater use will not increase in response to surface water reductions [*Dale and Dixon*, 1998].

Compared with other modeling approaches, the rationing model offered a simple and flexible response to short-run water cutbacks, while it only offered a limited flexibility in the short run. This is because growers will try to shift cropping patterns or adopt new technology to make long-term decisions to maximize profit or crop production.

The USARM model places far fewer constraints on farmer response to water cutbacks than rationing model does. Maximizing potential yield is what drives all decisions, like shift to low-water-using crops, acreage adjustment and irrigation efficiency improvement. The comparison between these two models is shown in Table 2.1.

2.3 Research gap

As reviewed above, previous studies examining farm profitability determinants often include farmer and farm household characteristics, farm management and financial characteristics. There are only a few studies considering the water usage and climate factors, which are critical inputs related to farm profit and agriculture. Thus, this study will employ the proportion of irrigation water withdrawals to control water use factor, involve temperature and precipitation as climate factors to figure out how climate changes affects the farm profit.

Table 2. 1 Comparison between USARM and Rationing model.

	USARM Model	Rationing Model
Purpose of modeling	Simulates the effects of change in input prices and water supply on input use and output	Predicts the changes in crop acreage and crop revenue (gross and net) caused by changes in water supply
Model method	Nonlinear programming: Objective production function with seven input categories (land, irrigation water, labor, capital, fertilizer, chemicals and energy/other inputs) subject to resource constraints, which is used to stimulate an equilibrium in a comparative static setting	Linear programming: ranking crops by net revenue per acre-feet of water and fallow to meet the constraint
Adaptation strategies	Medium term adjustments including: acreage adjustments, changing crop mix, and improve irrigation technology	Short-run response: Fallow until the water supply constraint is met
Price change	Response to the output price change	Treat the prices as a constant
Advantage	Permits much more response to water cutbacks Lower revenue lost	Simple linear programing; Realistic for responses to temporary water supply cutbacks
limitation	Complexing non-linear programing model, hard to run	Gets extreme corner solution, usually lower-return crops cease completely, while higher-value crop production unaffected. May overestimated revenue losses

3 Methodology and Data Analysis

This section presents the econometric methods to explain farm income and interpret the effect of water use and climate factors on net farm income. It describes each variable included in the model, explains the sources of dataset and how I manipulated the data used in the model. Finally, I offer the descriptive statistics for multiple variables in the model.

3.1 Theoretical model

In the study, I will use the ordinary least squares (OLS) method to explain farm profit statistically. OLS is a method for estimating the unknown parameters in a linear regression model. OLS chooses the parameters of a linear function of a set of explanatory variables by minimizing the sum of the squares of the differences between the observed dependent variable (values of the variable being predicted) in the given dataset and those predicted by the linear function.

The model is specified as follows:

$$Y_{fp} = f\left(X_w, X_c, X_f, X_d\right)$$

In the regression, I use net farm income per irrigated water withdrawals as a measurement of farm profitability Y_{fp}. I consider several factors influencing the dependent variable. Those factors include water use factors X_w, climate conditions X_c, financial characteristics X_f and demographic factors X_d. Water use factors include a variable measuring the share of total irrigation water that is from surface water (as opposed to groundwater) sources. Relying on surface water has advantages and disadvantages for farm profitability. Pumping costs are, on average, much lower for surface water supplies, so this might increase profitability. Yet, for many surface water users, the timing of water deliveries is determined by the irrigation district, so farmers may have less control over when they apply irrigation water [*Frisvold and Deva*, 2012]. Lack of control over the optimal time to apply irrigation water might reduce profits.

Climate conditions include climate and weather variables for average precipitation, average maximum and minimum temperatures. Precipitation is especially important, because the area with abundant water is likely to support more agricultural diversity and more robust agricultural economics [*Anderson*, 2013]. Demographic data incorporates farmer experience and education. I predict there will be higher net farm income with the increasing of farmer experience. This expectation is consistent with previous study [*Mafimisebi*, 2008]. Additionally, I also included some market economic-related variables to measure whether counties specialize in crop production or livestock production

3.2 Empirical model

The Empirical model is specified as follows:

$$\begin{aligned} Y_{fp} = \alpha\ &+ \beta_1 CSWR\ +\ \beta_2 CCRR\ +\ \beta_3 CCRR^2 + \beta_4 Experi + \beta_5 SPCP \\ &+ \beta_6 SPCP^2\ +\ \beta_7 STMAX\ + \beta_8 STMIN + \beta_9 WET3\ +\ \beta_{10} D2010 \\ &+\ \beta_{11} CA + \beta_{12} CO + \beta_{13} NV +\ \beta_{14} NM + \beta_{15} UT + \beta_{16} WY + e \end{aligned}$$

where the dependent variable Y_{fp} represents farm profits. The measurement is net farm income in thousand dollars per irrigated water withdrawals in thousands acre-feet. Thus, I will use the abbreviation NFI/AF to represent the farm profit in the following paper. The variable can measure the net farm income for any amount of irrigated water withdrawals. I derived the net income through cash receipts adding other income and subtracting production expenses, and adding the value of inventory change. I will also try to use other indexes to measure the net income, such as net income per irrigated acre, net crop income per acre, or net crop income per acre-feet.

The independent variable CSWR, is the proportion of irrigation-crop surface-water withdrawals in irrigation-crop total water withdrawals. The expected sign is ambiguous as noted above. Surface water is often lower cost, but growers may have less control over irrigation timing.

CCRR is the share of crop cash receipts in total farm cash receipts from marketing. Total cash receipts also involves livestock and product cash receipts from marketing. $CCRR^2$ is the square of crop cash receipts ratio. I assume that the proportion of crop cash receipts will show a quadratic relationship with net income, so I use square term to capture this effect. Using this variable with test the hypothesis that county farm profits will depend on how specialized the county is in crop versus livestock production. The quadratic specification can account for a variety of relationships. The specific relationship will be tested in the regression results.

The variable $Experi$ is the average number of years of farming experience principal operators in a county have. Data are available through the USDA Census of Agriculture.

SPCP, STMAX and STMIN measure the average precipitation, maximum temperature and minimum temperature during the growing season for each county in 2005 and 2010. The annual precipitation, maximum temperature, and minimum temperature are available, but annual averages smooth out seasonal variability. Therefore, growing season averages in 2005 and 2010 are used, rather than annual averages to capture the actual conditions during the crop growing period. I hypothesize that there is a quartic relationship between precipitation and NFI. With the increasing of rainfall, farm net income will increase until some optimal level of precipitation. Beyond this optimal level, NFI will decline with further increases in precipitation. For the maximum temperature, I assume that there is a negative relationship with net farm income. However, I hypothesize that farm income is positively associated with minimum temperature. Warmer winters imply more frost-free days that allow for longer growing seasons, multi-cropping, and production of higher valued fruit and vegetable crops.

WET3 is a dummy variable. I define that if the 3-month Standardized Precipitation Index (SP03) is positive, then t the WET3 dummy equals to one, otherwise it is zero. The SPI is a normalized index monitoring the severity of drought events. The SPI takes on positive values when seasonal rainfall is above long-term averages. It takes on negative values when seasonal rainfall is below long-term averages.

D2010 is year dummy variable used to capture structural change over different years. If the data are from 2010, year dummy variable equals one, otherwise it is zero.

Putting all the explanatory variables together, the regression equation estimated is:

$$
\begin{aligned}
Y_{fp} = \alpha + \beta_1 CSWR - \beta_2 CCRR \ + \ \beta_3 CCRR^2 + \beta_4 Experi + \beta_5 SPCP \\
- \beta_6 SPCP^2 - \ \beta_7 STMAX \ + \beta_8 STMIN + \beta_9 WET3 \\
+/- \beta_{10} D2010 + \ \beta_{11} CA + \beta_{12} CO + \beta_{13} NV + \ \beta_{14} NM + \beta_{15} UT \\
+ \beta_{16} WY + e
\end{aligned}
$$

where e is a stochastic error term and the α and β terms are regression coefficients to be estimated.

3.3 Data sources and process

This section will describe our data construction. To fix ideas, I start from the sources where our data comes from (section 3.3.1), and then describe in more detail how I processed the data (section 3.3.2). Finally, I will report the descriptive statistics for the dependent and independent variables (section 3.3.3).

3.3.1 Data sources

The data used to measure components contributing to farmer net income covered 236 counties in seven Western U.S. states (Arizona, California, Colorado, Nevada, New Mexico, Utah and Wyoming) in 2005 and 2010.

1. Farm income data

The data of Farm Income and Expenses by county come from the Bureau of Economic Analysis (BEA) of the United States Department of Commerce. The farm income is the income received by farmers from sources like participation as laborers in production, owning a home or business, the ownership of financial assets, and from government and business in the form of transfers. The specific income categories in the dataset include farm proprietors' income and earnings, cash receipts from marketing, government payments and other incomes. The production expenses include feed purchased, livestock purchased, seed purchased, fertilizer and lime (incl. ag. chemicals 1978-fwd.), petroleum products purchased, hired farm labor expenses and all other production expenses.

2. Water use data: Irrigation crop surface water withdrawals and total irrigation surface water withdrawals

The estimated water use in the United States county-level for 2005 and 2010 comes from the United States Geological Survey (USGS). This dataset contains preliminary water-use estimates that are aggregated to the county level in the United States. USGS has published an estimate of water use in the United States every 5 years, beginning in 1950. The water use estimates dataset contains data on county population, total water withdrawals, groundwater use, and surface water use.

Details on the water-use categories also can be found in the dataset, which includes public supply, domestic, irrigation, thermoelectric power, industrial, mining, livestock and aquaculture water use.

3. Climate and weather data

I use the thirty years normal data (1971–2000) from the PRISM Climate Group to represent historical temperature and precipitation (Daly et al. 2008). This is a baseline dataset describing average annual maximum temperature (Tmax; °C), minimum temperature (Tmin; °C), and precipitation (ppt; mm).

The weather and drought data come from National Oceanic and Atmospheric Administration(NOAA), U.S. Department of Commerce. The major parameters in this dataset are sequential climatic division monthly maximum, minimum and average temperatures (deg. F. to 10ths, national temperature to 100ths), precipitation (inches to 100ths), Standardized Precipitation Index (SPI), and Palmer Drought Indices (PDSI: Palmer Drought Severity Index, PHDI: Palmer Hydrological Drought Index, PMDI: Modified Palmer Drought Severity Index, and ZNDX: Palmer "Z" Index) in 2005 and 2010. This dataset is based on the climate division, rather than the county-level. Therefore, to merge with other county level datasets further, I assigned climate division data to counties.

3.3.2 Data process

After collecting the county-level data from multiple sources, I merged those four datasets through the identity ID: Geofips or Fips, keeping the variable I needed to use for running regression later, and dropped unnecessary variables. In total, I have 472 observations among 236 counties of seven western states in 2005 and 2010.

First, I merged the Farm Income and Expenses data from BEA with water usage data from USGS. I call the new dataset as BEA and USGS dataset, and I calculated several indices as follows,

1) Net income including corporate farms in thousand dollars per crop irrigated land in thousand acres ($/acre).

2) Net income including corporate farms in thousand dollars per crop irrigated water withdrawals land in thousand acre-feet ($/AF).

3) Crop cash receipts from marketing (thousands of dollars) per crop irrigated land in thousand acres ($/acre).

4) Crop cash receipts from marketing (thousands of dollars) per crop irrigated water withdrawals in thousand acre-feet ($/AF).

5) Upper bound estimate of net crop income (in thousand dollars): [Crop cash receipts + value of inventory change, crops] - [Seed purchased expenses + Fertilizer and lime (incl. ag. chemicals 1978-fwd.) expenses]. This is the gross margin from crop sales minus crop specific input expenses from the BEA data. Some expenses, such as for feed, are strictly for livestock production, while others, such as fertilizers are strictly for crop production. Other inputs, such as labor or fuel, cannot be allocated between crop and livestock production. These last variables are not included as expenses even though some of the expenses went to crop production. For this reason, this net crop income measure is an upper bound estimate.

6) Upper bound estimate of net crop income per crop irrigated land ($/acre).

7) Upper bound estimate of net crop income per crop irrigated water withdrawals ($/AF).

8) Crop cash receipts ratio (CCRR, percentage): Crop cash receipts over total cash receipts from marketing: [Cash receipts: Crops] / [Cash receipts from marketing (thousands of dollars)] × 100%.

9) Irrigation-crop surface water withdrawals ratio (CSWR, percentage): Irrigation crop surface water withdrawals / total irrigation surface water withdrawals × 100%.

Second, I merged climate division weather and drought data from NOAA with annual precipitation and temperature data to get a new dataset, which is called climate and weather data, and then it was again merged with income and water usage datasets from BEA and USGS.

Once the needed variables were identified and the initial data gathered from the various sources, two problems become apparent. One is how to deal with missing data and the other is how to assign the climate division to county observations. First, the values of crop irrigated acres, crop irrigated water withdrawals and irrigation-crop surface water withdrawals are all missing in 2005 dataset. In 2010 dataset, observations are missing for some counties. For those missing values, I used the value of total irrigated acres, total irrigated water withdrawals, total irrigation surface water withdrawals to substitute for crop irrigated acres, crop irrigated water withdrawals, and irrigation crop surface water withdrawals separately. The new variables include water use for golf courses, but this is a very small percentage of irrigated water use in any county. For the second problem, the climate division information is offered on the website of National Weather Service Climate Prediction Center. In some cases, the boundaries of a county were entirely within a single division. For these counties, the division value was assigned to the county. In other cases, a county might span two or more divisions. In these cases, counties were assigned data from divisions that made up the majority of their crop acreage.

Finally, climate division weather and drought data were merged with other county level observations.

3.3.3 Data analysis

1. Farm net income per irrigated water withdrawals

For the dependent variable, farm net income per irrigated water withdrawals measures the average farm net income from the irrigated water withdrawals. It has 472 observations in total, including 13 (around 2.8%) missing values, and the summary of descriptive statistic for dependent and independent variables is shown in Table 3.1. There are 2.1% and 3.0% missing values in 2005 and 2010 separately. Most of the missing values came from highly urban counties with very little agricultural production. Therefore, those counties were not included in the regression analysis.

When comparing the distributions of farm net income per acre foot among 2005 and 2010, almost half of counties have negative and zero net income in 2010, and the net income values in 20.8% counties are between zero and one hundred dollars per AF. However, in 2005 only 19.5% counties had negative and zero net income, while 41.6% counties had positive, but less than one hundred dollars per AF net incomes, as shown in Figure 3.1. The minimum and maximum profits in 2010 are also lower than the profits in 2005. General agricultural prices were higher in 2010 than 2005, so there is not a simple price-based explanation for this difference. As evidenced by the spatial Figure 3.2 and Figure 3.3, farm profitability differs not only from state to state but also from county to county.

2. Net income per irrigated land

Another dependent variable I experimented with was net income per acre, which measures the average farm net income from the irrigated land. The distribution of farm profit from irrigated land had similar pattern with farm net income from water use, as Figure 3.4 shows. Comparing the distributions of farm net income per acre among 2005 and 2010, there are 50.9% counties having negative and zero net incomes in 2010, while there are only 19.3% counties in 2005. The distribution of net farm income per acre in 2005 is relatively even. The average profitability of farm in 2005 is also higher than that in 2010, when using the NFI/acre as the measurement.

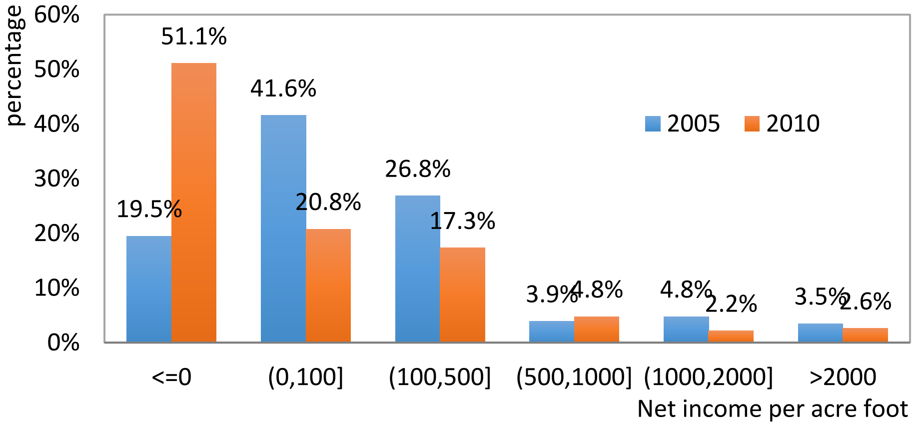

Figure 3. 1 Distribution of farm net income per irrigated water withdrawals.

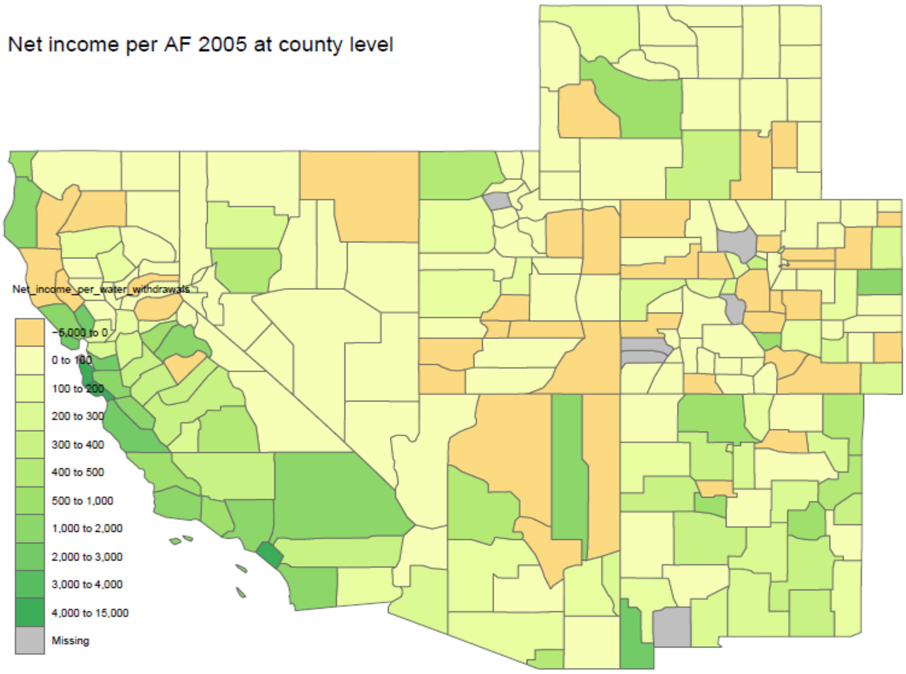

Figure 3. 2 Spatial distribution of net farm income in 2005 at county level.

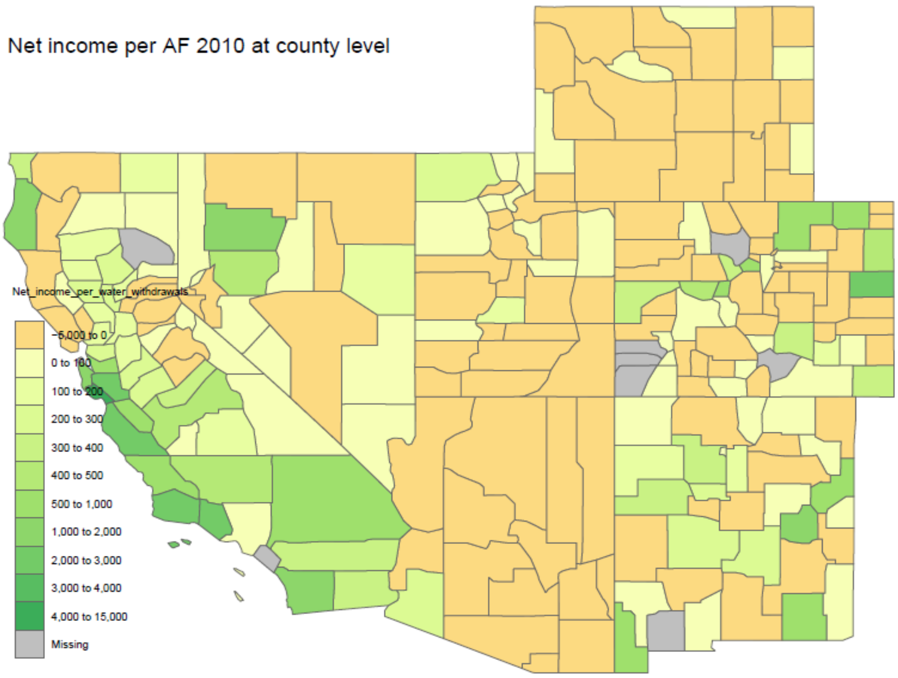

Figure 3. 3 Spatial distribution of net farm income in 2010 at county level.

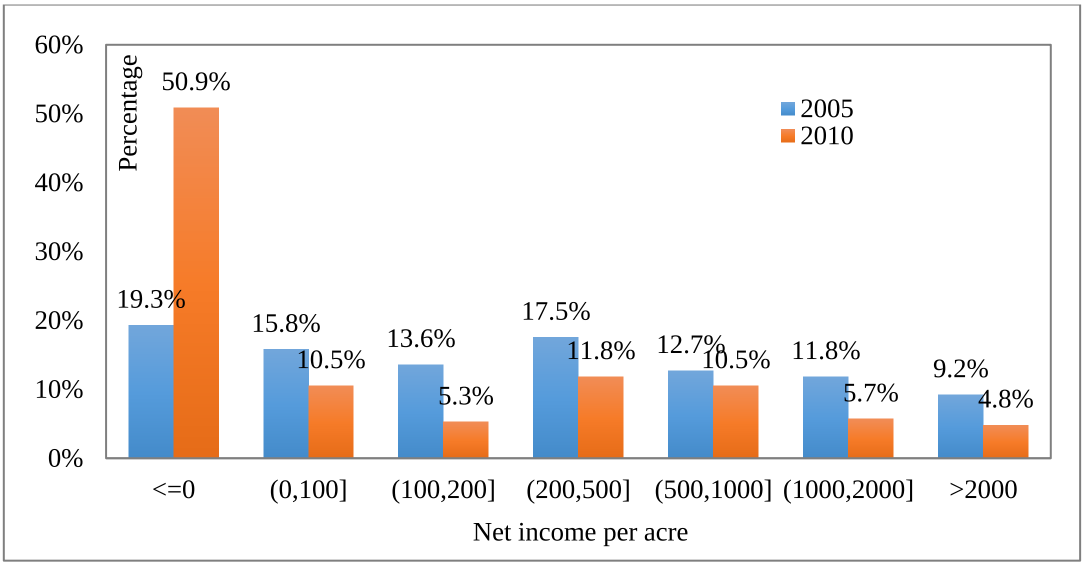

Figure 3. 4 Distribution of farm net income per irrigated water withdrawals.

3. CSWR (Crop surface water withdrawals ratio)

This independent variable, the crop surface water withdrawals ratio, measures the ratio of irrigation-crop surface water withdrawals (of irrigation-crop total water withdrawals). Among the seven western states, most of counties have high crop surface-water use ratios. For example, 59.49% of counties in 2005 and 60.34% of counties in 2010 with the ratio between 0.7 and 1.0. For the irrigation-crop total water withdrawals, it also included irrigation-crop ground-water withdrawals. Therefore, the higher value of the variable indicates that counties used surface water as a primary irrigation water source.

4. CCRR (Crop cash receipts ratio)

The histograms of the crop cash receipts ratio in 2005 and 2010 are shown below. Most of counties had lower crop cash receipts (around 0.05 to 0.45), which means higher livestock cash receipts.

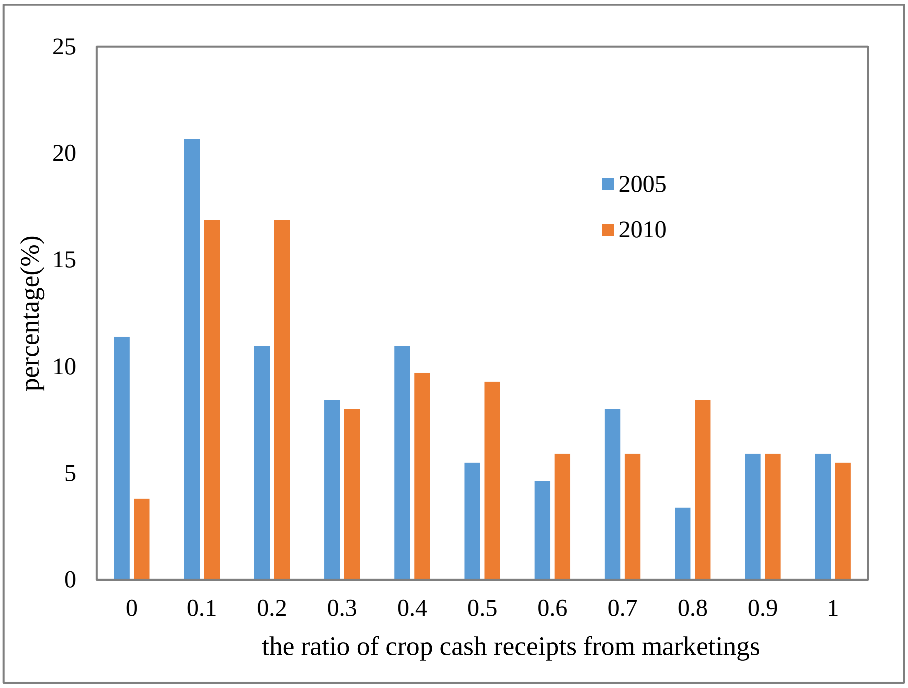

Figure 3. 5 Distributions of crop cash receipts ratio comparison in 2005 and 2010.

5. Annual precipitation, maximum and minimum temperatures

Annual precipitation measures average rainfall in millimeter among 30 years. The lowest rainfall is 95.36 mm per year and highest value is 2,549.27 mm. Around 75% of county rainfall levels are under 561.71 mm per year and about 76% of the precipitation are between 200 mm and 600 mm per year. The distribution of the western rainfall data is a skewed distribution and not a symmetric one. The tail to the right of the peak is longer than the tail to the left of the peak, as the Figure 3.6 shows. Colorado, New Mexico and Wyoming had higher precipitation values on average, and Nevada is the lowest among seven western states, as the spatial map Figure 3.7 shows.

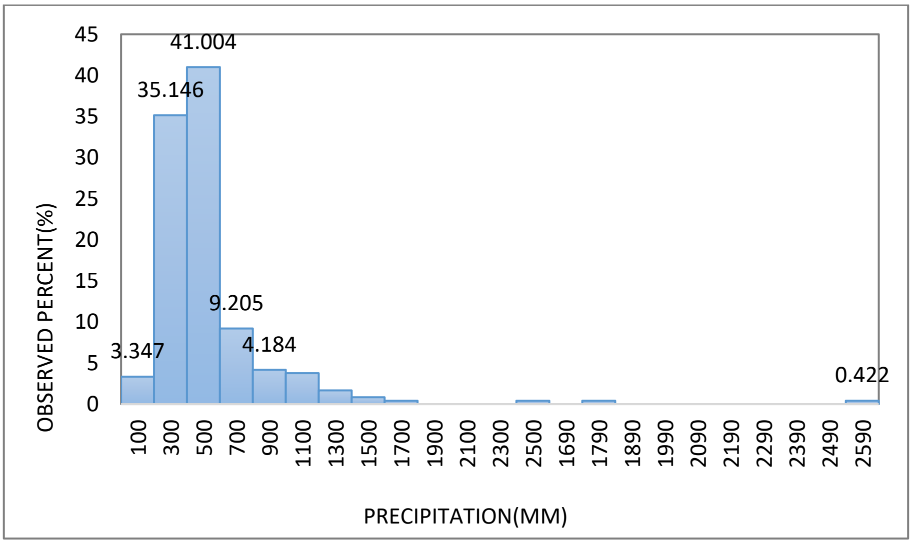

Figure 3. 6 Distribution of annual precipitation.

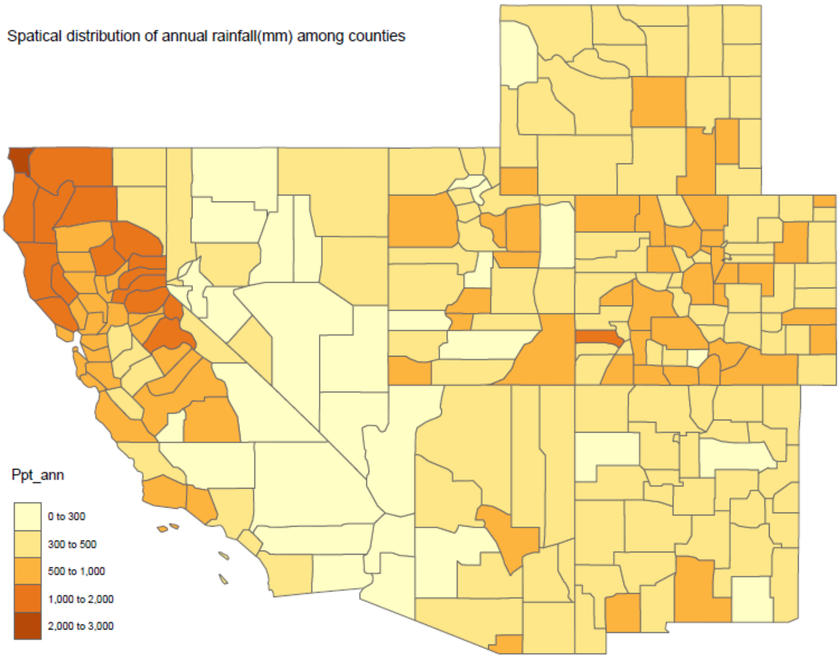

Figure 3. 7 Spatial distribution of annual precipitation.

The maximum and minimum temperatures approximately follow normal distribution, as the Figures 3.8 and 3.9 shown. The lowest maximum temperature is 7.1 °C per year, and highest maximum temperature is 30.53 ° C per year. The range of minimum temperature is from -7.67 ° C per year to 14.88 ° C per year. As the temperature spatial distribution map shown (Figures 3.10 and 3.11), California and Arizona have higher temperature, and Wyoming is the coldest state among the seven Colorado Basin states.

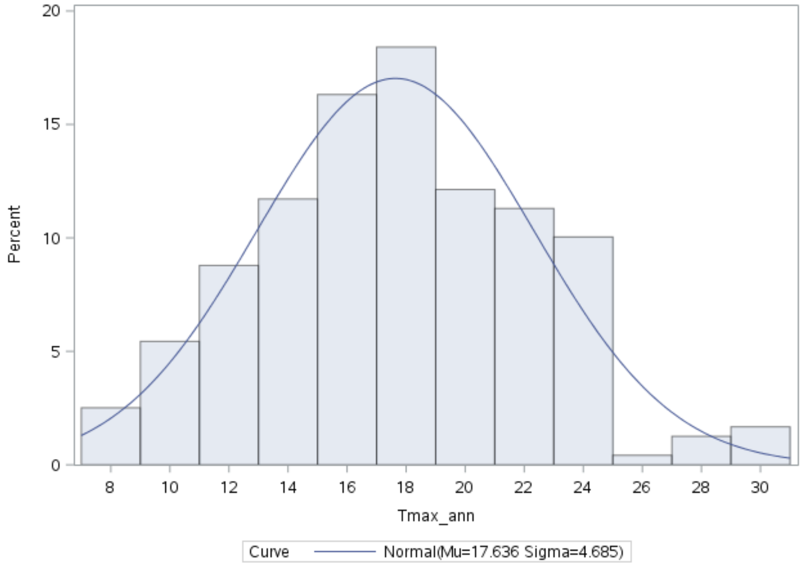

Figure 3. 8 Histogram of maximum temperature.

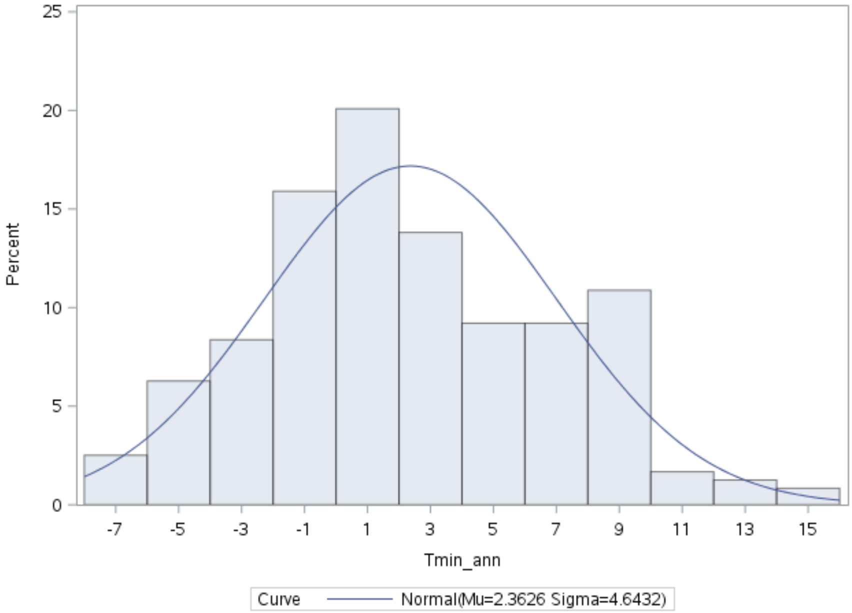

Figure 3. 9 Histogram of minimum temperature.

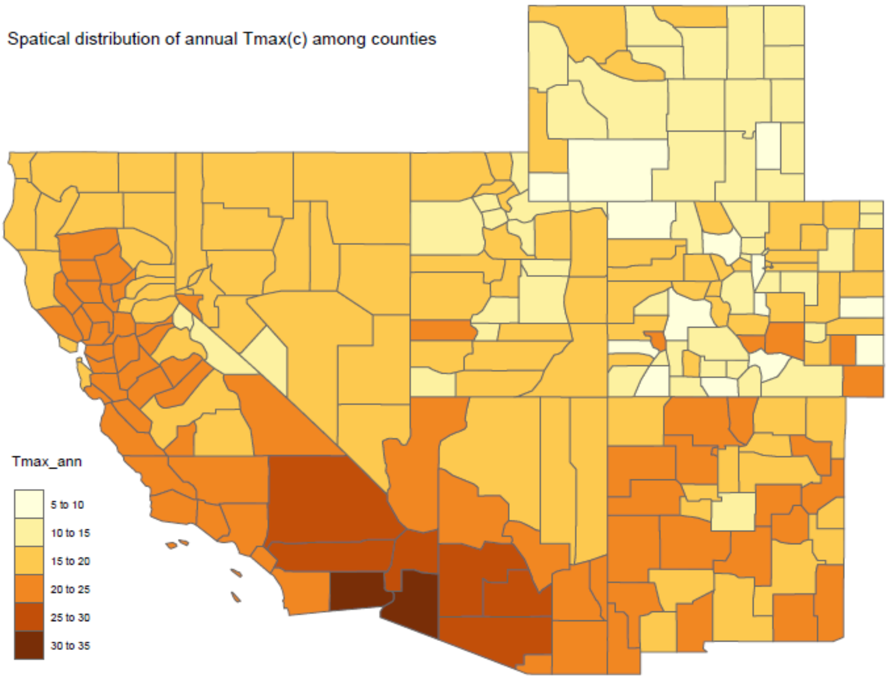

Figure 3. 1 0 Spatial distribution of maximum temperature.

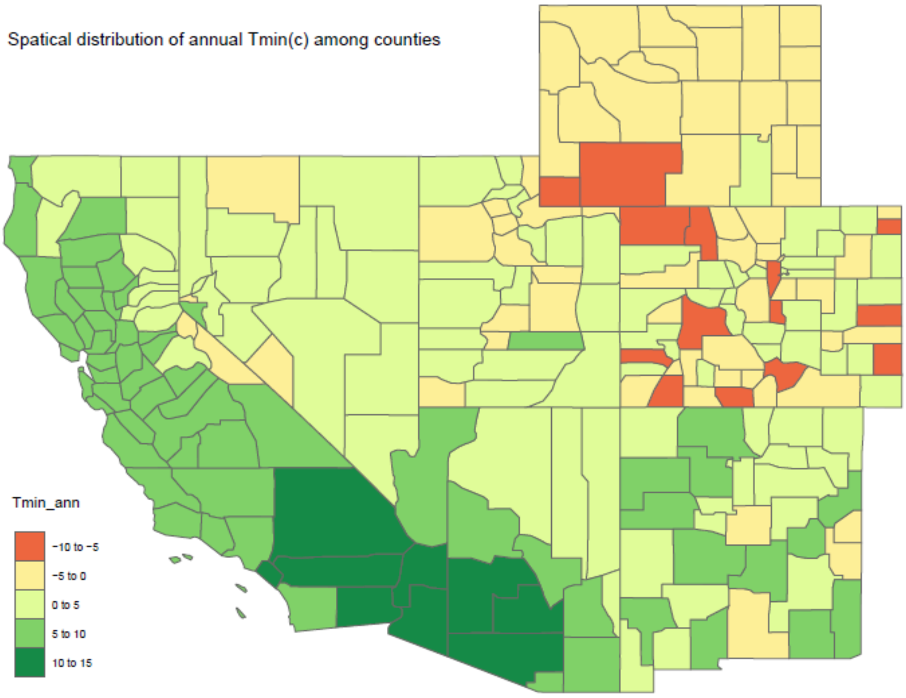

Figure 3. 1 1 Spatial distribution of minimum temperature.

6. Monthly precipitation, temperature and humidity indexes

I took the average of seven states for each weather variables and observed their monthly trends in 2005 and 2010, as the Figure 3.12 and Figure 3.13 shows. Those graphs indicate that the month with most rainfall has a relatively lower temperature. There are higher temperatures and lower rainfall from May to September, which is a prime growing season of many crops. In contrast, December, January and February had higher precipitation on average. Therefore, precipitation levels are a very important factor, because they can mitigate the need for irrigation water.

The rainfall index WET3 among seven states and 236 counties indicates that there are 63.14% counties in 2005 and 59.32% counties in 2010 with wetter than normal conditions.

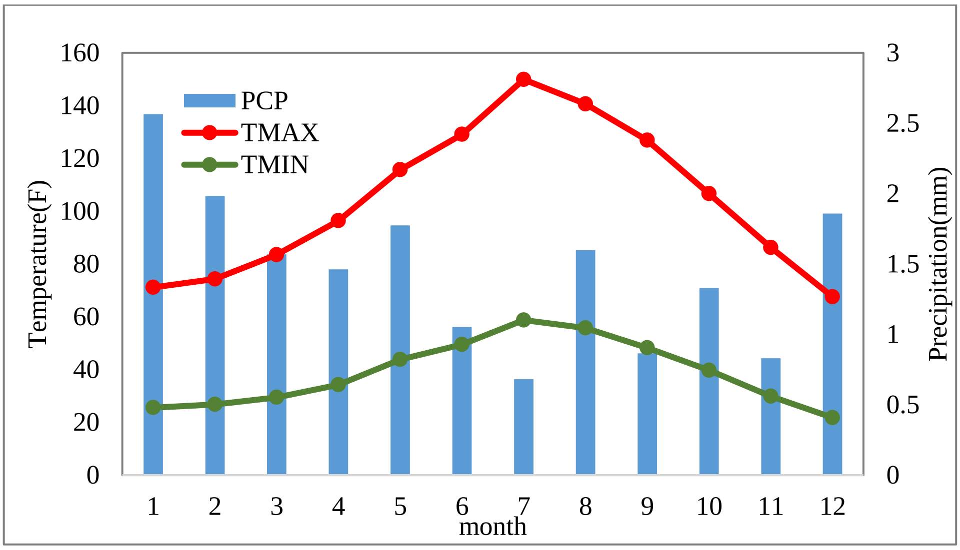

Figure 3. 1 2 Average monthly rainfall and temperature in 2005.

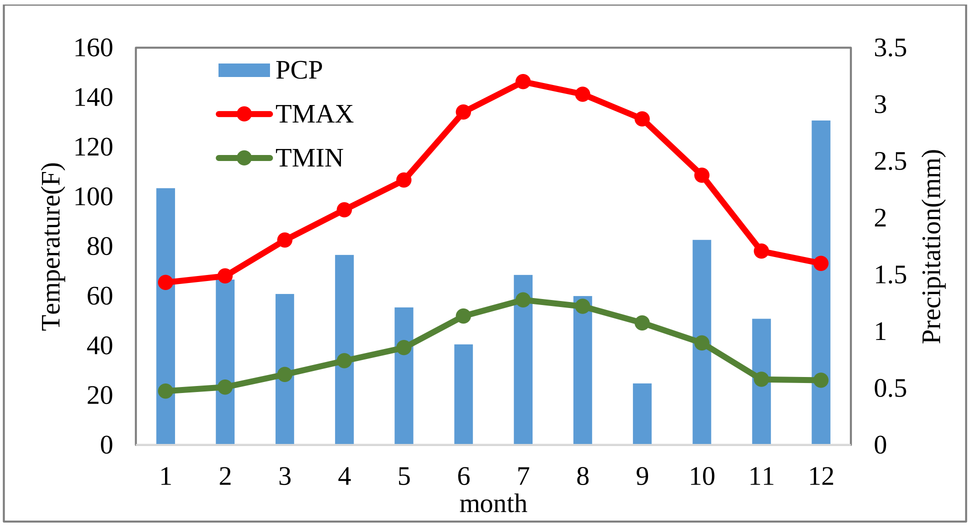

Figure 3. 1 3 Average monthly rainfall and temperature in 2010.

Table 3. 1 Descriptive statistics.

Variable Category	**Variable Name**	**N Miss**	**N**	**Std Dev**	**Minimum**	**Maximum**	**Mean**	**Variable Definition**
Dependent variable	Net income per water withdrawals	13	459	922.513	-5,762.890	11,304.460	182.221	Net income including corporate farms per crop irrigated water withdrawals ($/AF)
	Net income per irrigated land	17	455	1,598.010	-8,190.480	14,471.070	337.616	Net income including corporate farms per crop irrigated acre ($/acre)
	Crop cash receipts per water withdrawals	12	460	3,882.300	0.000	59,966.440	928.975	Crop cash receipts from marketing per irrigated water withdrawals ($/AF)
	Net crop income per water withdrawals	145	327	3,331.850	-141.092	47,036.040	697.562	Upper bound estimate of net crop income per crop irrigated water withdrawals ($/AF)
Water usage	CSWR (%, Crop surface water withdrawals ratio)	9	463	35.161	0.000	100.000	68.154	Irrigated-crop surface water withdrawals / Irrigated-crop total water withdrawals × 100%
Financial characteristics	CCRR (%, Crop cash receipts ratio)	17	455	30.145	0.634	99.654	40.201	[Cash receipts: Crops] / [Cash receipts from marketing] × 100%
Demographic	Experience	0	472	3.677	8.900	34.800	24.321	principal operators' average years on present operation (years)
Climate variability and weather	SPCP	0	472	15.172	1.067	61.925	31.314	Average precipitation for growing season(mm)
	STMAX	0	472	6.390	63.320	101.620	80.254	Average maximum temperature for growing season(F)
	STMIN	0	472	6.356	35.340	71.700	50.400	Average minimum temperature for growing season(F)
	WET3	0	472	0.488	0.000	1.000	0.612	a dummy variable: if SP03>0, then equal to 1
Other variable	D2010	0	472	0.501	0.000	1.000	0.500	a dummy variable: if year=2010, then equal to 1

Note: SP03 is Three-month Standardized Precipitation Index. SP03<0 means rainfall deficit; SP03>0 means rainfall surplus.

4 Results and Discussion

This chapter presents the results from the models and discusses the effects of climate and weather variables on the net farm income in the western states. Next, it estimates the possible economic effects of water cutbacks in a rationing model framework. Finally, this section, addresses limitations in the study and offers future research directions.

4.1 Statistical results

4.1.1 NFI/ AF as the dependent variable

Estimation results for farm net income using an OLS model are reported in Table 4.1. The model includes 16 variables (water use, climate and demographic variables), with observations from 236 counties of seven South Western states in 2005 and 2010.

The share of water use coming from surface water (as opposed to groundwater sources) is strongly negatively associated with net farm income. Result show that an increase of irrigation-crop surface water ratio (CSWR) by 1% would lead to a decrease of net farm income per acre foot by $7.75.

For the financial characteristic variable, as expected, crop cash receipts ratio (CCRR) is a significant determinant for net farm income. It shows a quadratic relationship with a minimum net income when considering the square term. The quadratic results (Table 4.1) indicated that farm net income is minimized when the crop cash receipts are 41.34% of total cash receipts from marketing. Hence, when the crop cash receipts ratio is lower, with each additional percentage of crop cash receipts received from total market, there would be a $1.22 net income decreasing per acre foot. But if the ratio is greater than 41.34%, farm net income will increase as the proportion increased. This suggests that net income is higher if a county specializes in either crop production or livestock production.

Contrary to the prior expectation, the sole demographic variable experience is insignificant for seven southwestern states. That is plausible because this variable is a county average and there may just be too little variation across counties for a regression model to find and effect. Effects of experience might be easier to estimate with individual farm level data, rather than county average data. Mean experience is approximately 24 years. However, the minimum value for county experience in the West is 9 years, while the maximum value is 35 years.

For climate variability and weather variables, precipitation and its square term are significant. The results indicate that at low levels of precipitation, income falls with increasing precipitation until precipitation reaches 42 mm. After that, additional precipitation increases farm net income. Huong [*Huong et al.*, 2018] also found the relationship between household revenue and weather variables were non-linear, but with an inverted U-shaped relationships. They found net revenue decreased as temperature and rainfall increase in the dry season.

Aligned with our hypothesis, average maximum temperature is negatively and significantly correlated with net farm income. The results indicated that an increase of temperature by one Fahrenheit leads to the reduction of income per acre foot by $96.2. On the one hand, it means that higher temperature might damage crops or, perhaps, force farmers to harvest before the yield has reached its maximum value [*Powell and Reinhard*, 2016]. On the other hand, it is possible that higher temperatures make crop water requirement increase. Then farmers have to withdraw more water to irrigate, which increases labor and irrigation costs. However, a higher minimum temperature increases net income. Every 1 F increase in the average minimum temperature leads to an income increase of $93.5 per acre foot. This may be because higher winter temperatures may facilitate year-round agricultural production and growing of higher value fruit and vegetable crops.

As expected, the WET3 dummy variable has a positive relationship with NFI. The estimation results from state dummy variables indicated that Colorado, New Mexico, Utah and Wyoming both have higher net farm income significantly, compared with that in Arizona. I will discuss the variability of states farm profit in the next section.

4.1.2 Alternative measures of farm profitability

Using net farm income per irrigated land as the measurement of farm profitability, I tried to figure out the influence of independent variables on the NFI per acre. The regression results are shown in Table 4.2 below. I also use crop cash receipts per acre foot and the upper bound estimate of net crop income per acre-feet (which is defined as [Crop cash receipts + value of inventory change, crops] - [Seed purchased expenses + Fertilizer and lime (incl. ag. chemicals 1978-fwd.) expenses]) as the alternative measure of farm profit. Crop cash receipts per acre foot measures the direct revenue that farmers obtain from crop, while the latter measures the upper bound of net crop income. Using different dependent variables to run regressions, the results are shown in Table 4.2. The minimum temperature variable has a positive and significant effect on NFI/AF, NFI/acre and crop cash receipts per acre foot. But it has no effect on the crop net income. The reason might be that only 319 observations are used in the regression since around 32% are missing values. The other different influences on each dependent variable is the year dummy variable. As the results show, the net farm income per acre or per acre foot in 2005 is significant higher than in 2010. However, crop revenue and net income from crops was not significantly different between 2005 and 2010. From the comparison of regression results, I conclude that four measurements of farm income have similar relationship with those of water use, farm specialization, weather, and climate variability factors.

Table 4. 1 Estimation results of OLS Model for net farm income.

Dependent variable is farm net income per irrigated water withdrawals($/AF)

Variable	**Parameter Estimate**	**Standard Error**	**Pr > |t|**
Intercept	4,765.515***	1,325.801	0.000
Irrigated crop surface water / irrigated surface water	-7.747***	1.286	<.0001
Cash receipt from crop/from marketing	-19.594***	5.295	0.000
Square of (Cash receipt from crop/from marketing)	0.237***	0.053	<.0001
Experience of principal operator (yrs)	-17.489	16.798	0.298
Average precipitation for growing season (mm)	-57.198***	13.545	<.0001
Square of precipitation	0.675***	0.214	0.002
Average Tmax for growing season (F)	-96.205***	36.708	0.009
Average Tmin for growing season (F)	93.591**	38.057	0.014
WET3 (dummy)	173.337*	96.945	0.075
D2010 (dummy, year=2010)	-237.757**	115.257	0.040
CA	322.896	218.057	0.139
CO	866.590***	228.532	0.0002
NV	183.149	278.924	0.512
NM	728.885***	213.078	0.001
UT	569.128**	221.619	0.011
WY	675.245**	270.388	0.013

R-square: 0.318, N=448

Note: *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

Table 4. 2 Results comparison of model between different dependent variables.

Independent dependent	NFI/AF	NFI/ACRE	Crop cash receipts per AF	Net crop income per AF
Irrigated crop surface water / irrigated surface water	-6.040*** (1.220)	-8.465*** (2.128)	-18.204*** (5.325)	-15.000*** (5.742)
Cash receipt from crop/from marketing	-17.260*** (5.026)	-35.011*** (8.727)	-72.938*** (21.907)	-51.674** (24.549)
Square of (Cash receipt from crop/from marketing)	0.215*** (0.051)	0.392*** (0.088)	1.031*** (0.221)	0.726*** (0.241)
Experience of principal operator(yrs)	-16.449 (16.591)	-19.042 (28.681)	25.729 (72.157)	-21.536 (82.781)
Average precipitation for growing season (mm)	-56.280*** (11.630)	-101.695*** (20.268)	-141.230*** (50.709)	-144.417*** (53.174)
Square of precipitation	0.833*** (0.186)	1.410*** (0.325)	1.793** (0.812)	1.864** (0.842)
Average Tmax for growing season (F)	-87.865*** (31.182)	-103.722* (54.448)	-296.841** (134.907)	-256.682* (145.145.046)
Average Tmin for growing season (F)	73.854** (31.247)	97.548* (54.506)	237.027* (135.427)	203.369 (145.352)
wet3 (dummy)	93.604 (86.973)	205.831 (150.671)	35.885 (379.245)	135.340 (394.028)
D2010 (dummy, year=2010)	-233.309** (115.817)	-651.823*** (200.618)	-671.562 (502.954)	-490.181 (554.747)
Intercept	5,291.147*** (1,119.995)	6,879.094*** (1,954.206)	16,340*** (4,857.970)	15,237*** (5,272.576)
N	448	444	452	319
R-square	0.283	0.274	0.222	0.190

Note: *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

4.2 Impacts of climate change on net farm income

The agriculture production and net farm income in the western United States is strongly influenced by the local climate conditions, as the regression results show above. A comprehensive analysis of weather and climate variability can help farmer to take adaptive behaviors such as changing crops and crop varieties, adjusting planting and harvest dates to lessen yield losses from climate change and guide policy makers to allocate the supply water rationally.

Water is a vital input to agricultural production and linked to farm income, so varying precipitation patterns have a significant impact on agriculture growth. However, the impact of regional precipitation is different in different regions. The IPCC [*Ipcc*, 2007] predicts an overall increase in precipitation, and the prediction shows large increases in the southern USA and India but also significant decreases in the tropics and sub-tropics. The low latitudes region except India shows the decreases. However, changes in seasonal precipitation may be more relevant to agriculture than annual mean precipitation.

In this study, in order to examine effects of climate variability on net farm income, I employ growing season precipitation, maximum temperature, and minimum temperature variables to run the regression, which is called the core model (model I). To distinguish the different influences of annual climate and growing season weather changes on the net income, I also ran two other models, model II and model III. Based on core model (model I) Model II includes additional three variables, i.e., annual precipitation, annual maximum and minimum temperature variables into the regression model. Model III only estimates the impact of annual climate variables on farm profitability, excluding seasonal precipitation and temperature variables based on model II. In Model I, precipitation in the growing season has a significant quadratic relationship with NFI. However, when involving both annual average and growing season variables in model II, the annual precipitation is not significant, while seasonal rainfall is still significant and negatively correlated with net farm income per irrigated water withdrawals. If I separate the annual precipitation, as shown in the last column of Table 4.3, the annual precipitation shows a negative relationship with NFI (one-millimeter rainfall increase leads to a decrease of $0.44 per acre foot). For growing season precipitations in model I and model II, there is a similar magnitude and negative relationship. For the extreme temperature variables, an annual maximum or minimum temperature increase of 1 ℃, that will cause farm income to decrease by $159 per AF or to increase by $198 per AF in model II. Note, thought that if both minimum and maximum temperatures increased by 1 ℃ at the same time (as might happen under climate change), the net effect on farm income would be smaller. However, the extreme temperature variables for growing season are not significant.

Table 4. 3 Comparison of three models on different climate variables.

Dependent variable is farm net income per irrigated water withdrawals ($/AF)

Variable	**Seasonal data (Model I-Core model)**	**Annual &seasonal climate data (Model II)**	**Annual data (Model III)**
Intercept	4,765.515	6,343.247	4,701.207
Irrigated crop surface water / irrigated surface water	-7.747***	-7.720***	-8.289***
Cash receipt from crop/from marketing	-19.594***	-22.735***	-26.741***
Square of (Cash receipt from crop/from marketing)	0.237***	0.256***	0.300***
Experience of principal operator (yrs)	-17.489	-12.683	-22.849
Average annual precipitation (mm)		0.016	-0.439**
Average annual maximum temperature (℃)		-159.085**	-234.208***
Average annual minimum temperature (℃)		198.152***	273.074***
Average precipitation for growing season (mm)	-57.198***	-55.218***	
Square of precipitation	0.675**	0.635**	
Average Tmax for growing season (F)	-96.205**	-60.629	
Average Tmin for growing season (F)	93.591**	51.516	
WET3	173.337**	115.453	
D2010	-237.757**	-255.430**	-83.100
CA	322.896	25.731	480.227**
CO	866.590***	1,064.399***	997.720***
NV	183.149	204.119	474.581
NM	728.885***	950.078***	881.635***
UT	569.128**	545.784**	641.550**
WY	675.245**	751.993**	726.935**
R-square	0.318	0.345	0.308

Note: *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

4.3 Estimation of the economic effects of water reductions

A rationing model estimates changes in crop acreage and crop revenue caused by changes in water supply, as Chapter 2 described. Under an exogenous, fixed price assumption, crops are ranked by gross revenue per acre-feet of water applied to the crop. The model assumes that county with the lowest returns fallows all of its cropland first to meet the water reduction target. If the target is not meet then the county with the next lowest returns fallows all of it land. This process continues until the water reduction target is hit. We calculate the decreasing of gross revenue per acre-feet and change of irrigated acres respectively, when there are 10%, 15%, 25% and 40% water cutbacks, as Table 4.5 shows. The proportion of irrigation land use declining are higher than the percentage of water cutback, while the crop revenue decreases only by 2%. The rationing model treated the entire region in aggregate, but previous studies already found that the largest reductions in acreage in response to water cutbacks would come from lower-value crops grown in areas holding junior rights to Colorado River water. The higher-value crops grown in the senior rights regions were unaffected [*Frisvold and Konyar*, 2012].

Although fallowing irrigation is one response to drought, growers also have alternative, lower-cost solutions, like changing crop mix or implementing deficit irrigation. When farmers used a combination of those strategies compared with fallowing land, the cost of responding to water shortages was greatly decreased [Frisvold and Konyar, 2012]. Thus, the rationing model is a simple and easy-to-implement option to estimate the upper-bound of cost to agriculture of water supply shock.

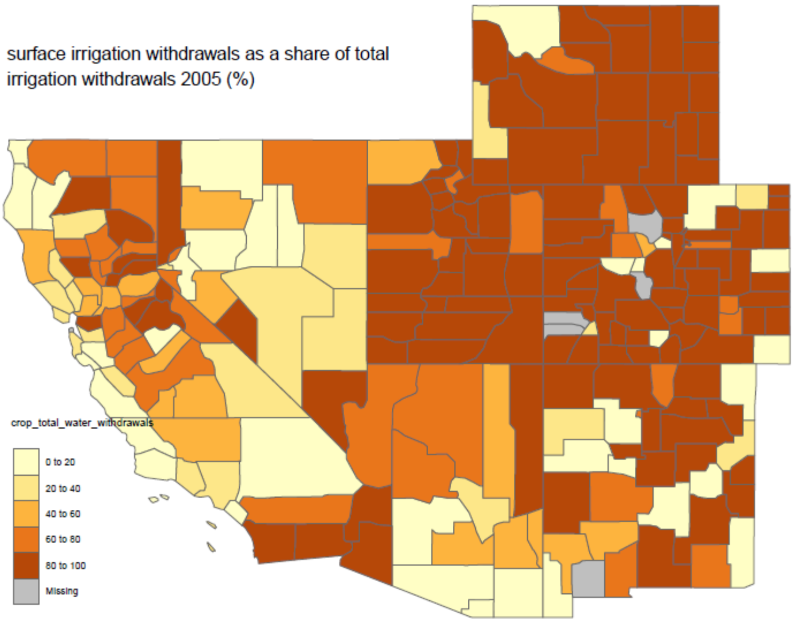

Figure 4. 1 Spatial distribution of surface irrigation water withdrawals rate.

Table 4. 4 The effects of water supply cutbacks.

Percentage of water supply cutbacks	water supply after cut (million AF)	Change of Irrigated acres (million acres)	%Change of Irrigated acres	Change of Crop cash receipts (million dollars)	%Change of Crop cash receipts
10%	53.83	3.28	19.8%	137.60	0.2%
15%	50.84	4.41	26.6%	410.33	0.5%
25%	44.86	4.61	27.8%	498.15	0.6%
40%	35.89	5.84	35.3%	919.47	1.0%

4.4 Limitation and future work

Data shortages and time constraints are the main aspects restricting the capacity of this study. First, it is difficult to get current and consistent data on agricultural water use. The water-use information from the USGS are collected and compiled every five years for each state with most recent surveys from 2010, 2005, 2000, and so on. I only analyzed two discrete years of data. As we have known, the climate factors not only develop and fluctuate over time, but also cause farm income to vary from year to year. Using data from a single year (or small sample of years) will not capture such fluctuations. Thus, we should collect more detailed panel data rather than aggregated cross-sectional data, in order to improve estimation.

Second, using counties as the analysis unit without access to farm-level data raises an important concern about the spatial and temporal heterogeneity for farm level. Claassen and Just (2011) proved that spatial and temporal heterogeneities in county-level agricultural economics studies can be a problem. Intra-county heterogeneity could also be important to this study as well. In our study, I only collect the data from USGS, NOAA and NASS at the county level. Thus, it is hard to understand and estimate the water use at the individual farm level. It would be very interesting to see the effect of water on farm profitability by simulating and analyzing state-level, county-level, and individual farm level data.

5 Conclusion and policy recommendations

This study examined the factors that affect the farm profitability. I analyzed the relationship between net farm income per water withdrawals and a cross-sectional set of water use, financial characteristic combined with important climate variables for seven southwestern states in 2005 and 2010. The results showed that with the increase of surface water withdrawals for crop-irrigation, farm profitability significantly decreased. This was true even though surface water is often less expensive to deliver to fields. Frisvold and Deva (2012) found that for many smaller farms, the timing of water deliveries was determined by the irrigation district, so farmers did not control the timing of their irrigations. Further research is needed to determine whether this lack of control is a major constraint on farm profitability

A simple rationing model is applied to examine potential costs of large reductions in water use that might occur under land fallowing programs. If fallowing were concentrated in areas with the lowest gross revenues per acre foot of water, even substantial reductions in water use would have only a minimal effect on the value of regional production.

Regression results, though, suggest that the costs of fallowing programs could either be quite small or quite large depending on where and when they were applied. The regression results suggest estimates of these costs can fluctuate substantially with weather variation.

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