Agricultural Irrigation's Responses to Federal Crop Insurance in the United States

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Abstract

Irrigated agriculture is the largest fresh water user in the United States. Growing pressure on water resources due to climate change and population growth has prompted renewed focus on irrigation water demand. Currently the U.S. crop insurance program covers more than 80% of cropland and 130 crops. There have long been concerns that crop insurance would have a wide range of distortionary effects on farmers' economic decisions. In this article, therefore, we focus on how crop insurance affect farmers' irrigation decisions. Related studies overlook the impacts of climate and soil quality while studying the causal relationship between crop insurance and irrigation water demand, therefore, may suffer omitted variable bias. Our study is the first to conduct a comprehensive analysis of the implications of federal crop insurance on irrigated water use while accounting for soil quality and climate variation. We first develop a conceptual framework to deduce testable hypotheses about how crop insurance may affect water use. Based on the county-level irrigation and crop insurance data from 2000 to 2015 with a five-year step, our preliminary results suggest that a one thousand acres increase in insured crop acreage, on average, decreases fresh water demand for crops by 4.14 thousand cubic meters in a year at the national level, which come mostly from surface water withdrawals. Our preliminary findings have theoretical justifications; however, these empirical results contradict existing studies which claim that federal crop insurance puts upward pressure on fresh water withdrawals from aquifers.

Keywords: Crop Insurance, water demand for Crops, Groundwater, Surface Water

JEL Codes: Q15, Q19, Q25

Agricultural Irrigation’s Responses to Federal Crop Insurance in the United States

Introduction

Agriculture is the largest water user in the United States (Weber, Key, and O ’donoghue, 2016). However, growing pressures on water supplies due to rising temperature, shifting precipitation patterns, growth in populations and income, and intensified ecological needs have prompted renewed focus on irrigation water demand across the United States (Postel et al., 1996; Vörösmarty et al., 2000; Gleick and Palaniappan, 2010; Weber, Key, and O ’donoghue, 2016). For example, since 2010, recurrent drought has been contributing to surface water shortage and groundwater overdraft in the arid and semi-arid regions of the country (Ward 2013; Famiglietti 2014; Howitt et al. 2014; Olen et al. 2015).

The risk-averse farmers across the nation are adopting numerous crop insurance policies. Deryugina, and Konar (2016) point out that there are ambiguities how federal crop insurance premium subsidy shapes farmers water use decisions under unfavorable climate and existing state-level water rights. Undoubtedly, higher amount of insurance premium subsidy encourages farmers to buy insurance and ensure a guaranteed level of farm income. Deryugina, and Konar (2016), however, argue that ensuring certain level of income in advance, federal crop insurance programs affect farmers water use decision in multiple ways. For example, it raises the moral hazard problems among insured farmers. It also encourages farmers to use more water for irrigation to fulfill irrigation requirements for certain types of insurance programs (Manning, Goemans, and Mass, 2017). At the same time, there are plenty of other crop insurance programs that requires normal irrigation in order to become eligible for an insurance claim (Deryugina, and Konar, 2016). As a result, in an unfavorable climate condition and limited water use rights, farmers having suitable crop insurance may decide not to use water beyond normal irrigation, while farmers without similar insurance might have decided to irrigate more water to save their crops.

On the other hand, it's those crop insurance programs that require more irrigation will compel insured farmers to irrigate in a failed crop yield situation. Moreover, since crop insurance programs are expanding coverage to more crops (Shields, 2015) and more land acreage, therefore, inclusion of marginal land and water intensive crops will put more upward pressure on water demand for irrigation under climate change over a normal climate scenario. These raises a relevant empirical question whether federal crop insurance premium subsidy causes net upward or downward pressure on water resource sustainability. In other words, given irrigated agriculture's sensitivity to crop insurance policies, climate, and water scarcity, providing a clear understanding of the implications of federal crop insurance premium subsidy on water use in agriculture across the country under changing climate is a contribution to policy evaluation.

Federal crop insurances policies provide supports to farmers for about 130 crops including variety of fruit trees, dry peas, citrus, pasture, rangeland, and forage (Shields, 2015). Major crops are now insured in every single county across the United States. Four crops—corn, cotton, soybeans, and wheat—however, are planted on 70% of total insured land (Shields, 2015). Federal crop insurance covers 87% of total corn acreage planted, 96% of total cotton acreage planted, 88% of total soybeans acreage planted, and 84% of total wheat acreage planted. The 2014 Farm Act, however, has raised government cost for crop insurance substantially. The crop insurance premium subsidy is the largest cost component of federal spending on crop insurance programs. In its 2017 baseline projections, the Congressional Budget Office has estimated that the crop insurance program will cost $7.7 billion annually between 2018 and 2027. Government pays, on average, about 62% of total premium for yield-based and revenue-based crop insurance policies, and almost 100% of total premium for catastrophic coverage (Shields, 2015). Farmers have responded to the increased federal crop insurance premium subsidy by enrolling 86% more acres; 158 million acres in 2000 to over 294 million acres in 2014 (Weber, Key, and O ’donoghue, 2016). By encouraging risk-averse farmers (a) to switch marginal lands from pasture to cultivation, and (b) to shift to insured crops, increased crop insurance subsidy premium has been increasing input use (Babcock and Hennessy, 1994; Wu, 1999; Wu and Adams, 2001; Young, Vandeveer, and Schnepf, 2001; Goodwin, Vandeveer and Deal, 2004; Walters et al., 2012).

Increase in crop insurance premium subsidy affect irrigation decisions. “some crop insurance programs require full irrigation to insure land as irrigated” (Manning, Goemans, and Mass, 2017). For example, to insure a farm land as irrigated, farmers in Kansas require to apply a minimum amount of water needed to produce the irrigated APH yield (Senate Bill 272, 2012). A growing body of literature, however, indicates that crop insurance leads to riskier farming practices either by adding marginal lands into farming practices or planting a crop which may lead to low yield or changing the behavior of inputs use (Babcock and Hennessy, 1996; Smith and Goodwin, 1996; Wu, 1999; Barnett et al., 2002; Goodwin and Smith, 2003; Deal, 2004; Goodwin et al., 2004; Tronstad and Bool, 2010; Cole et al., 2014; Karlan et al., 2014; Cai et al., 2015; Mobarak and Rosenzweig, 2015; Claassen et al., 2016; Deryuginaa, and Konar, 2017). Irrigation plays a crucial role in the U.S. economy by making significant contribution to the value of agricultural outputs and water supplies. On-farm irrigation relies on three sources of water: about 55% irrigation water comes from aquifers, about 35% from water delivery system, and about 10% from surface water (Stubbs, 2015). Five states—Nebraska, California, Arkansas, Texas, and Idaho—inhabit about 52% of total irrigated acres. However, irrigated farms in almost half of the US states produce more than 50% of the total market value of crops sold across the nation (Vilsack and Clark, 2014). Although the market share of irrigated acres has declined in the west in the last two decades, however, irrigation in the east has been growing over time. For example, NASS data on irrigated acreage suggest that eastern states such as Mississippi, Georgia, South Carolina, Maryland, Delaware, and New Hampshire have experienced more than 40% increase in irrigated acres between 1997 and 2013.

However, due to numerous issues such as changing climate, volatility of agricultural prices, and gradual increase of crop insurance premium subsidies across the nation, on-farm agricultural water use raises a number of policy concerns. Many stakeholders have become interested in policies associated with irrigation water use. For example, many farmers are concerned about possible cuts of their water rights that may affect their agricultural practices as well as their eligibility of certain types of crop insurance claims. Many municipalities across the nation are concerned whether agricultural water use will affect urban and industrial water supply. Environmental activists are concerned whether on-farm irrigation practices will aquatic ecosystem and biodiversity either by degrading water quality or by depleting water reservoirs or both.

Despite the importance of on-farm irrigation and federal crop insurance policies in U.S. agriculture, to our knowledge, no study has considered the implications of gradual increase in the federal crop insurance premium subsidy on water resource use in agriculture under the ongoing changes in climate across the United States. Deryugina, and Konar (2016) is the only study that investigates implications of crop insurance policies on water use in agricultural sector in the United States. The major limitation of their study is that Deryugina, and Konar (2016) examine causal impact of crop insurance on irrigation water use without incorporating climate change data and irrigation costs that include fertilizer prices and gas price. Moreover, their analysis mainly delineates effects of the 1994 Federal Crop Insurance Reform Act on water withdrawal for irrigation across the nation. Therefore, our study is the first, to our knowledge, to conduct a comprehensive analysis of the implications of federal crop insurance on irrigated water use under changing climate across the United States.

In this paper, we develop a conceptual framework to deduce testable hypotheses about how climate change and crop insurance may affect irrigation water uses. We analyze county-level irrigation and crop insurance data from 2000 to 2015 with a five-year step using fixed effects and instrumental variable approaches to deal with county level fixed effects and endogeneity issues. We have instrumented (a) insured crop acres by the subsidy rate at 75% coverage level; (b) fertilizer price index by the average of the monthly natural gas price during the growing season; and (c) crop price index by the lagged crop stocks in December.

Our preliminary results suggest that a one thousand acres increase in insured crop acreage, on average, decreases irrigation water demand for crops by 4.14 thousand cubic meters in a year at the national level, holding all else constant. Moreover, a one thousand acres increase in insured crop acreage, on average, decreases surface water demand for crops by 5.52 thousand cubic meters in a year at the national level. Our preliminary findings have theoretical justifications that we have stated in the proposition 2 below. Results also reveal that increase in input costs, on average, decreases water demand for crops while increase in crop prices put upward pressure on fresh water demand for crops at the national level. We also find that effects of increase in crop prices dominate the effects of input costs in terms of fresh of withdrawals for crops, which comes mainly from surface water. The coefficients for the ground water withdrawals in most of our models are statistically insignificant. However, Deryugina, and

Konar (2016) claim that 1% increase in insured acreage leads to barely 0.15% increase in fresh surface water withdrawals for crops while it causes 0.275% (i.e., 0.19 km^3) increase in groundwater withdrawals (Deryugina, and Konar, 2016. Pp. 7). We, therefore, infer that our preliminary findings contradict existing studies which claim that federal crop insurance puts upward pressure on irrigation water withdrawals from aquifers.

The remainder of this paper is organized as follows. Section 2 outlines the theoretical framework that is used to develop empirical strategy for this study. Section 3 provides brief description of the econometric approach that we have used to analyze the data. Section 4 describes data, variables, and identification strategy. Section 5 presents regression results. Section 6 contains conclusions and plan for further improvement of this study.

Theoretical Framework

To develop our empirical strategy, using the widely used von Neumann-Morgenstern utility function, we first investigate how ongoing climate change may affect irrigation water withdrawals in the absence of actuarially fair crop insurance program. After that, we incorporate actuarially fair crop insurance contract into the framework. we find that in the absence of crop insurance contract, ongoing climate change is likely to encourage a risk averse farmer to irrigate more at the intensive margin, however, it will have no effect on water use at the extensive margin. On the contrary, federal crop insurance programs disincentivize irrigation withdrawals at the intensive margin, however, it becomes unclear at the extensive margin. Combining all these likely effects of crop insurance on irrigation water withdrawals at the intensive and extensive margins, it becomes unclear whether federal crop insurance programs incentivize or disincentivize irrigation water uses. In other words, the net effect of actuarially fair crop insurance program on irrigation water uses remains ambiguous in our framework.

Consider a representative risk averse farmer in a representative year who faces two states of the nature: the low state (l) such as drought under which the farmer experiences low return (π_l) with probability p, and high state (h) under which the farmer experiences high return (π_h) with $1-p$, where $\pi_l < \pi_h$. We also assume that the farmer faces two water allocation choices for farming: do not irrigate or irrigate, denoted by subscripts 0 and 1 respectively. We assume that farmer will adopt only one of these two water allocation choices for a given farm. Once the farmer adopts a water use choice $i \in \{0,1\}$ for a farming season, it provides him a random return π_i. We assume that in low state irrigation causes higher return over no irrigation because irrigation is likely to increase crop yields, i.e., $\pi_{0l} < \pi_{1l}$. In high state the farmer does not need to irrigate. Even if the farmer irrigates in a high state then, due to irrigation cost, overall return could be lower or equivalent to the likely return generated by doing no irrigation in the high state, i.e., $\pi_{1h} \leq \pi_{0h}$. These assumptions can be summarized as:

Assumption 1: $\pi_{0l} < \pi_{1l} < \pi_{1h} \leq \pi_{0h}$.

We now assume that the farmer's preference can be expressed using a utility function such that $u'(\cdot) > 0$ and $u''(\cdot) < 0$. The farmer with concave utility function will prefer irrigation. In this framework, we capture the likely changes of irrigation water use in intensive margin and extensive margin.

We define Δ as the difference between expected utility obtained from farmer's decisions for not to irrigate and irrigate the intensive margin in the absence of crop insurance: $\Delta = E[U(\pi_0)] - E[U(\pi_1)]$, where $E(\cdot)$ is the expectation operator. It is likely that when there exists no crop insurance, any change in nature will influnece farmer's irrigation deciosn. Therefore, to examine how climate change affects farmer's decision to irrigate or not to irrigate, we study the likely change in Δ due to increase in p, holding everything else constant, by the following expression:

$$\frac{\partial \Delta}{\partial p} = U(\pi_{0l}) - U(\pi_{0h}) - U(\pi_{1l}) + U(\pi_{1h}) < 0 \tag{1}$$

The equation (1) indicates that an increase in the probability of low return, p, will assign more weight on low state returns and less weight on high state returns; it will decrease the average returns from farmer's decision to irrigate and not to irrigate. Note that farmer's decision to irrigate has higher return in the low state and low return in the high state. In other words, harsh climate is likely to encourage the farmer for irrigation practices in the intensive margin.

Now we incorporate land expansion (i.e., extensive margin) in the framework without considering a mathematical model. In the absence of crop insurance program, the risk averse farmer prefers to keep the land idle by participating in land conservation programs such as CRP that ensures a fixed return $\bar{R}$ to the farmer. This scenario can be expressed as $EU(\bar{R}) > \max[EU(\pi_0), EU(\pi_1)]$. We assume that climate change does not affect $\bar{R}$, however, it decreases expected utility of returns from farmer's decision to irrigate or not to irrigate. Therefore, it is likely that climate change causes land abatement. Therefore, we can infer that in the absence of crop insurance program, climate change will not affect water use at the extensive margin, however, it may abate the extensive margin. We summarize these suppositions in the following proposition.

Proposition 1. *In the absence of crop insurance contract, an increase in the probability of low return state will encourage irrigation practices at the intensive margin, and hence will disincentivize water sustainability. However, it will have no effect on water use at the extensive margin.*

Effect of Federal Crop Insurance

We now incorporate actuarially fair crop insurance contract into the framework. For simplicity, we assume that if the farmer adopts an irrigation choice $i \in \{0,1\}$, then the insurance contract guarantees average return $\bar{\pi}_i$ to the farmer. In the low state, the farmer receives an indemnity payment $\bar{\pi}_i - \pi_{il},\ i \in \{0,1\}$. In the high state, however, $\pi_{ih} > \bar{\pi}_i$ which leads to zero indemnity payment to the farmer. Thus, the actuarially fair premium of the crop insurance contract to the farmer is $p(\bar{\pi}_i - \pi_{il})$. We define the net returns from adopting irrigation choice $i \in \{0,1\}$ in the presence of actuarially fair crop insurance under state $j \in \{l,h\}$ as π'_{ij}. Therefore, we can express the returns in the presence of crop insurance as:

$$\pi'_{ij} = \begin{cases} \bar{\pi}_i - p(\bar{\pi}_i - \pi_{il}) \\ \pi_{ih} - p(\bar{\pi}_i - \pi_{il}) \end{cases} \tag{2}$$

We now define Δ' as the difference between expected utility obtained from adopting irrigation choice $i \in \{0,1\}$ in the presence of actuarially fair crop insurance contract at the intensive margin: $\Delta' = EU(\pi'_0) - EU(\pi'_1)$. After some derivation (see Appendix A), we obtain $EU(\pi'_0) - EU(\pi'_1) > EU(\pi_0) - EU(\pi_1)$, which implies that $\Delta' > \Delta$. This expression suggests that in the presence of crop insurance the difference between the expected utility obtained from farmer's decisions to not to irrigate and irrigate at the intensive margin is higher than its counterpart in the absence of crop insurance. Therefore, we can infer that actuarially fair crop insurance program encourages the farmer not to irrigate at the intensive margin.

Now we examine, in this framework, how crop insurance will affect farmer's water use decision at the extensive margin. Actuarially fair crop insurance ensures a raise in the utility of the risk averse farmer by ensuring a guaranteed return in the low state for water use choices

$i \in \{0,1\}$. It is possible that, the presence of insurance contract, the expected utility obtained from farmer's decision to irrigate at the extensive margin will exceed the utility obtained by keeping crop land idle that ensures a fixed return $\bar{R}$ to the farmer, i.e., $U(\pi_1') > U(\bar{R}) > U(\pi_0')$. This scenario implies that actuarially fair insurance contracts encourage farmers to irrigate at the extensive margin. On the other hand, it is also possible that the expected utility obtained from farmer's decision in favor of not to irrigate will exceed the expected utility obtained by keeping crop land idle. We can express this scenario as: $U(\pi_0') > U(\bar{R}) > U(\pi_1')$. This scenario implies that insurance contracts encourage farmers for not to irrigate at the extensive margin.

Now combining these likely effects of actuarially fair crop insurance contracts on farmer's water use decision at the intensive and extensive margins, it becomes unclear whether federal crop insurance programs incentivize or disincentivize irrigation water uses. Presence of this ambiguity, therefore, demands an empirical investigation of the likely effects of crop insurance on irrigation water uses. We summarize these suppositions in the following proposition.

Proposition 2. *Ceteris paribus, actuarially fair crop insurance program disincentivizes irrigation at the intensive margin, however, it becomes unclear at the extensive margin. Therefore, the net effect of actuarially fair crop insurance program on irrigation water uses remains ambiguous.*

The proposition 2 reveals that theory does not predict the net effect of crop insurance on irrigation water use, which leaved us an empirical question.

Empirical Model

We are interested in examining the causal relationship between irrigation water withdrawals for crops and federal crop insurance in a county under the ongoing climate change. We estimate a linear and a quadratic econometric model as specified below:

$$Y_{ct} = \beta_0 + \beta_1 Ins_{ct} + \beta_2 \boldsymbol{X}_{ct} + \beta_3 \boldsymbol{X}_{ct}^2 + \alpha_c + \epsilon_{ct}, \tag{3}$$

Where Y_{ct} is a vector of dependent variables that includes total fresh water withdrawals for crops, fresh surface water withdrawals for crops, and fresh groundwater withdrawals for crops in county $c \in \{1,...,N\}$ in the year $t \in \{2000,2005,2010,2015\}$; β_0 is a constant; β_1 is the coefficient for the insured crop acreage; $\boldsymbol{\beta}_2$ and β_3 are coefficient vectors to be estimated for the other explanatory variables and their quadratic terms respectively; $\boldsymbol{X}_{ct}$ is a vector of control variables such as fertilizer price index, crop price index, temperature, precipitation, and time trend; $\boldsymbol{X}_{ct}^2$ is a vector of square terms for temperature and precipitation. Moreover, α_{ij} stands for time-invariant factors for county *c* that may affect water withdrawals for crops, such as geographical location and soil characteristics. Finally, ϵ_{ct} is an error term.

A key econometric issue is the endogeneity of insured acres, fertilizer price index, and crop price index variables in model (3). To address the endogeneity of these explanatory variables, we apply a panel data instrumental variable approach with county fixed effects. We explain instrumental variables in the next section. We employ fixed effects models to control for unobserved time-invariant factors that might affect water withdrawals for crops such as a county's geographical location and soil quality.

Data and Variables

In this section, we discuss our data sources on irrigation withdrawals for crops, federal crop insurance, crop price, crop acreage, crop harvested, crop stocks, fertilizer price, natural gas price, temperature, and precipitation. We also discuss about instrumental variables that we have used in the study to address likely endogeneity issues. The key explanatory variables in our data set are based on county-level observations on federal crop insured acreage. However, we are unable to distinguish the intensive and extensive margin due to data limitation. We control for crop price index, fertilizer price index, maximum temperature, and average precipitation in the growing season for 2,946 counties for a five years interval between 2000 and 2015. We limit our data within this 16 years' time span due to unavailability of irrigation water withdrawals for crops data for the earlier years. Moreover, we construct our county-level data set for a five-year gap because USGS irrigation withdrawals for crops data are available in a five years interval. Our dependent variables are county-level groundwater withdrawals for crops, surface withdrawals for crops, and total irrigation water withdrawals for crops. Table 1 below provides the summary statistics for all three dependent variables, control variables, and instrumental variables. The data sources and other details of the variables are explained below.

Data on county-level irrigation withdrawals for crops state-by-state come from the USGS National Water Information System. This data set has been revised for some states and counties, based on data that has been made available since the previous circulars were published. The drawback of this data is that it does not provide county-level data for each available year between 1985 and 1995. Moreover, this data set does not provide irrigation withdrawals for crops for seven states that includes Mississippi, Missouri, Montana, North Dakota, Oklahoma, Texas, and Wisconsin.

Our data on federal crop insurance come from the Summary of Business Reports (SBR) that have been published by the US Department of Agriculture. SBR data provides information on county-level insured acreage, coverage levels, and subsidy premium. We use 75% coverage levels. We calculate subsidy rates for 75% coverage level by dividing subsidy premium by total premium for each county.

Our data on crop price, production, crop stocks in December, and harvested acreage come from surveys of the USDA National Agricultural Statistics Service (NASS). It provides county level annual data on acres planted for various field crops. However, we use data only for 18 major crops that includes barley, beans, canola, corn, cotton, flaxseed, lentils, mustered, oats, peanuts, peas, rice, safflower, sorghum, soybeans, sugarbeets, wheat, and alfalfa hay. We construct the Laspeyres price index by using state-level received prices and crop production for 18 crops by using 2010 as the base year. In year $t \in \{2000, 2005, ..., 2015\}$, the price index is defined as: $p_{it}^{a} = (\sum_{l=1}^{18} p_{lit} q_{li2010}) / (\sum_{l=1}^{18} p_{li2010} q_{li2010})$, where p_{lit} is the received price of crop $l \in \{1, ..., 18\}$ in state i, and q_{li2010} is the production of crop l in the base year 2010. We use Laspeyres price index as a proxy for expected aggregate crop price. However, due to unavailability of futures prices of few crops, we could not use the futures price as a proxy in this study. We first converted crop stocks data into tons and then calculate state level annual crop stocks in December for abovementioned 18 major crops.

We obtain annual national level fertilizer price index data from the USDA Economic Research Service. We control for fertilizer price because fertilize is the most crucial input for crop production. Moreover, on average, farmers incur 30% of total operating costs of major field crops and over 40% for corn due to fertilizer use. We expect that cost of fertilizers will affect farmers' crop acreage decision that will affect volume of insured acres in a county.

We obtain monthly national level natural gas price date from the U.S. Energy Administration (EIA). We construct average of the natural gas price for a year by using deflated monthly gas price data between April and July of that year. We use only the natural gas price because it is highly correlated with diesel price and electricity price (Hendricks and Peterson, 2012).

We also control for county specific maximum temperature and monthly average of daily mean precipitation for the growing season that includes days between April 1 and September 31 in a year. Data on temperature (in Celsius) and precipitation (in millimeters) come from PRISM model. Furthermore, we incorporate linear and quadratic time trend variables to capture technological advances over time in crop irrigation practices (e.g., micro-irrigation, sprinkler irrigation etc.).

Identification Strategy

To address the likely endogeneity of three explanatory variables—fertilizer price index, crop price Index, and crop insured acreage—we employ instrumental variables. We use average of the natural gas price for the growing season as an instrument for the fertilizer price index. The primary reason for this is that natural gas price does not directly influence farmers' crop acreage decision, however, it is correlated with fertilizer price index because nitrogen fertilizer contains natural gas as a component (Huang, 2007). We use lagged state level crop stocks as instrument for the crop price Index. Moreover, we use the subsidy rate at 75% coverage level as an instrument for the insured crop acreage in a county. We use 75% coverage level because it is the most commonly used coverage level during our study period. The primary reason for choosing subsidy rate as instrumental variable is that subsidy rate is not endogenous to county level crop production (Yu et al., 2017). Though there exists concern about the exogeneity of the subsidy rate in the post-2008 period due to its dependence on the national distribution of units, nevertheless, Yu et al. (2017) report robust results by employing the subsidy rate at 75% coverage level as an instrument in their study.

Regression Results

Table 2 shows the fixed effects estimates of the very basic relationship of irrigation withdrawals for crops with maximum temperature and average precipitation in a growing season. Columns 1, 2, and 3 in Table 2 show causal relationship between two climate variables with total irrigation water withdrawals for crops, surface water withdrawals for crops, and groundwater withdrawals for crops in the 41 states while columns 4, 5, and 6 presents their counterparts in the western states that includes twelve states— Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming, and Texas—where California, Idaho, and Texas inhabit the major share of total irrigated acres among the western states. Table 2 in general reveals that there is statistically significant and positive relationship between total water withdrawals for crops and maximum temperature both in the western states and across the nation. Specifically, one-degree Celsius increase in maximum temperature is associated with, on average, 4.8 Mgal/day (i.e., 6.62 million cubic meter in a year) additional withdrawals of fresh water for crops across the nation; and 17.20 Mgal/day (i.e., 23.74 million cubic meter in a year) in the western states, holding all other factors fixed. Columns 1, 2, and 4 suggest without any wonder that rise in temperature elevates irrigation water demand for crops, which is consistent with existing literature. Row 3, however, indicates that irrigation water demand is decreasing over time. One plausible explanation of this trend could be associated with innovation of more efficient irrigation technologies such as drift irrigation or sprinkler irrigation over surface irrigation.

Tables 2 and 3 together reveal that precipitation is statistically significant and positive and its squared term is statistically significant and negatively associated with both total water withdrawals and surface water withdrawals for crops both in the United States and the West. The correlation coefficient between precipitation and surface water withdrawals for crops is -0.37; and between precipitation and total water withdrawals for crops is -0.39. Therefore, one plausible reason for this non-linear relationship is that at low precipitation, farmers demand more surface water for their crops, however, high precipitation elevates soil moister that decreases the water demand for irrigating crop lands. The basic results we present in the Tables 2 and 3, however, suffer from the omitted variable bias.

Table 4 shows Fixed Effects-Instrumental Variable estimates of the causal relationship between crop insurance and water uses for crops. We have instrumented crop insured acres by the subsidy rate at 75% coverage level. Row 1 reveals that there is significant and negative relationship between insured crop acres and surface water withdrawals for crops while there is significant, however, positive relationship between insured crop acres and groundwater withdrawals for crops at the national level. However, these relationships are statistically insignificant in the west. Like Table 2, Rows 4 and 5 in Table 4 consistently reveals non-linear relationship between precipitation and total water withdrawals for crops; and precipitation and surface water withdrawals for crops. Moreover, time trend also remains consistent in Table 4.

Table 5 shows preliminary estimates of the full model in this study. It presents Fixed Effects-Instrumental Variable (FE-IV) estimates of the causal relationship between crop insurance and water uses for crops. To deal with endogeneity issues we have instrumented (a) insured crop acres by the subsidy rate at 75% coverage level; (b) fertilizer price index by the average of the monthly natural gas price during the growing season; and (c) crop price index by the lagged crop stocks in December.

Table 5 reveals that crop insurance has statistically significant and negative relationship with total fresh water withdrawals for crops and surface water withdrawals for crops at the national level. However, it becomes insignificant for the western states. The relationship with groundwater in statistically insignificant at all levels. Model (1) shows that the estimated coefficient of insured crop acres is -0.003, which indicates that a one thousand acres increase in insured acreage, on average, decreases irrigation water demand for crops by 4.14 thousand cubic meters in a year at the national level. Similarly, model (2) indicates that a one thousand acres increase in insured acreage, on average, decreases surface water demand for crops by 5.52 thousand cubic meters in a year at the national level. Our theoretical model justifies these empirical results because proposition 2 above states that, though the net effect of actuarially fair crop insurance program on irrigation water demand remains ambiguous, however, federal crop insurance program in general disincentivizes irrigation at the intensive margin. Our empirical results, therefore, suggest that the effect of crop insurance on irrigation water demand at the intensive margin dominates the effect of crop insurance on irrigation water demand at the extensive margin.

Like crop insurance, fertilizer price index has exactly similar relationships with total water withdrawals for crops, and surface water withdrawals for crops at the national level. Model (1) shows that the estimated coefficient of the fertilizer price index is -9.639, which indicates that one unit of fertilizer price index increase will decrease total fresh water irrigation for crops by 13.30 million cubic meters in a year at the national level. Similarly, the model (2) indicates that one unit of fertilizer price index increase will decrease fresh surface water withdrawals for crops by 11.24 million cubic meters in a year at the national level.

Crop price index, precipitation, and time trend, however, have statistically significant and positive relationship with total fresh water withdrawals for crops and surface water withdrawals for crops at the national level; and the respective coefficients are statistically insignificant for the west. Model (1) shows that the estimated coefficient of the crop price index is 325.768, which indicates that one unit of crop price index increase will increase total fresh water irrigation for crops by 450 million cubic meters in a year at the national level. Model (2) shows that the estimated coefficient of the crop price index is 299, which indicates that one unit of crop price index increase will increase the demand for surface water for crops by 413 million cubic meters in a year at the national level.

Now, comparing the likely impacts of one unit increase in the fertilizer price index and one unit increase in the crop price index, we find that crop price index has dominating impact on water demand for crops. Coefficients of the time trend in the model (1) and (2) capture the likely upward pressure on demand for fresh water for crops due to increase in crop prices and demand for agricultural produces over time. Moreover, we find that coefficients for the ground water withdrawals in most of our models are statistically insignificant. However, Deryugina, and Konar (2016), which is the closest work available until now, claim that increase in the demand for crop insurance policies leads to more groundwater withdrawals over surface water withdrawals for crops. Their findings indicate that 1% increase in insured acreage leads to barely 0.15% increase in fresh surface water withdrawals for crops while it causes 0.275% (i.e., 0.19 km^3) increase in groundwater withdrawals (Deryugina, and Konar, 2016. Pp. 7). We, therefore, infer that our preliminary findings contradict existing literature that claims crop insurance puts upward pressure on aquifers.

Conclusions

Despite growing interest among stake holders, only a few studies focus on irrigation water demand in the United States with likely omitted variable bias in those studies. In this paper we contribute to the renewed focus on irrigation water demand in the United States by omitting bias and addressing likely endogeneity issues. We analyze county-level irrigation and crop insurance data from 2000 to 2015 with a five-year step to examine the implications of federal crop insurance on irrigated water use while accounting for soil quality and climate variation. We develop a conceptual framework to deduce testable hypotheses about how crop insurance may affect irrigation water uses. We analyze unbalanced panel data set using fixed effects and instrumental variable approaches to deal with county level fixed effects and endogeneity issues. We have instrumented (a) insured crop acres by the subsidy rate at 75% coverage level; (b) fertilizer price index by the average of the monthly natural gas price during the growing season; and (c) crop price index by the lagged crop stocks in December.

Our preliminary results suggest that a one thousand acres increase in insured crop acreage, on average, decreases fresh water demand for crops by 4.14 thousand cubic meters in a year at the national level, holding all else constant. Moreover, a one thousand acres increase in insured crop acreage, on average, decreases fresh surface water demand for crops by 5.52 thousand cubic meters in a year at the national level. Our theoretical model justifies these empirical results. Theory predicts that, though the net effect of actuarially fair crop insurance program on irrigation water demand remains ambiguous, however, federal crop insurance program in general disincentivizes irrigation at the intensive margin. Our empirical results, therefore, suggest that effect of crop insurance on irrigation water demand at the intensive margin dominates the effect of crop insurance on irrigation water demand at the extensive margin. Moreover, we find that coefficients for the ground water withdrawals in most of our models are statistically insignificant. In other words, our preliminary results suggest that crop insurance does not put any pressure on groundwater.

Our preliminary findings contradict current studies which claim that federal crop insurance puts upward pressure on irrigation water withdrawals from aquifers. For example, Deryugina, and Konar (2016) claim that increase in the demand for crop insurance policies leads to more groundwater withdrawals for crops over surface water withdrawals. One plausible reason for this contradiction could be that earlier studies have used USGS irrigation water withdrawals data that include water withdrawals for all recreational lands including irrigation water uses in the golf courses and parks. Unlike those studies, we have analyzed more refined irrigation water withdrawals data, which is available only from the year 2000 until 2015. This implies that irrigation water data and the time frame of our study are different than those studies. Moreover, we have used different econometric approaches.

Conclusions in this study, however, come with few qualifications. First, one of our instruments, the subsidy rare at the 75% coverage level, raises concern about its exogeneity (Yu et all. 2017). Therefore, we are in search of a better instrument. Moreover, our dependent variables possess plenty of zero values that we actually observe; those zeros are not randomly determined. Therefore, to account for those observed zeros and to have more credible results, we will employ either PPML or the sample selection approach or both in the next version of this paper.

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Table 1: Summary Statistics; N=6,857; Year:2000—2015 in a five-year interval.

Variable	Mean	Std. Dev.	Min	Max
Dependent Variables				
Fresh Ground Water Withdrawals (Mgal/d)	15	71.501	0	1,639
Fresh Surface Water Withdrawals (Mgal/d)	23	112.315	0	2,739
Total Fresh Water Withdrawals (Mgal/d)	38	162.062	0	3,487
Explanatory Variables				
Insured Crop Acres (in Thousands)	91,594	136098	0	212,3813
Fertilizer Price Index (base year: 2010)	141	46.132	79	198
Crop Price Index (base year: 2010)	0.737	0.220	0.399	1.741
Average of Maximum Temperature (in C)	26	3.721	12	38
Average Precipitation (in millimeters)	92	34.406	0.61	229
Instrumental Variables				
Crop Stocks in December (in Tons)	1.03E+07	1.51E+07	0	6.07E+07
Average Natural Gas Price ($/1,000 cubic feet)	9.12	1.550	7.631	11.39
Subsidy Rate at 75% Coverage Level	0.525	0.181	0.133	0.87

Table 2: Fixed Effects Regression Results

	United States			Western States		
	Total Water	Surface Water	Ground Water	Total Water	Surface Water	Ground Water
	(1)	(2)	(3)	(4)	(5)	(6)
Average of Maximum Temperature	4.761***	4.052***	0.709	17.202***	11.371	5.831
	(1.126)	(1.439)	(0.739)	(5.816)	(7.414)	(3.835)
Average Precipitation	0.120***	0.149***	-0.029	0.927***	0.723*	0.205
	(0.037)	(0.043)	(0.021)	(0.356)	(0.401)	(0.195)
Time Trend	-5.602***	-5.829***	0.227	-27.804***	-31.589***	3.785
	(1.154)	(1.245)	(0.583)	(6.257)	(6.454)	(3.096)
Constant	-72.193**	-70.083*	-2.110	-85.099	7.421	-92.520
	(28.926)	(37.179)	(19.139)	(145.863)	(178.628)	(90.207)
Observations	6,833	6,833	6,833	996	996	996
Number of FIPS	2,306	2,306	2,306	358	358	358

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 3: Fixed Effects Regression Results with Quadratic Terms

	United States			Western States		
	Total Water	Surface Water	Ground Water	Total Water	Surface Water	Ground Water
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Average of Maximum Temperature	2.876	2.874	0.001	-34.835	-9.873	-24.962
	(8.581)	(13.469)	(6.012)	(61.035)	(102.370)	(48.090)
Square of Maximum Temperature	0.050	0.038	0.012	1.208	0.547	0.661
	(0.176)	(0.280)	(0.123)	(1.414)	(2.356)	(1.098)
Average Precipitation	0.500***	0.574***	-0.074	2.928***	2.731***	0.197
	(0.160)	(0.150)	(0.112)	(1.005)	(1.040)	(0.504)
Square of Average Precipitation	-0.002***	-0.002***	0.000	-0.016**	-0.015*	-0.001
	(0.001)	(0.001)	(0.000)	(0.006)	(0.008)	(0.003)
Time Trend	-5.918***	-6.181***	0.263	-27.527***	-31.953***	4.426
	(1.199)	(1.268)	(0.601)	(6.229)	(5.899)	(2.936)
Constant	-75.585	-85.722	10.137	404.801	150.513	254.288
	(106.183)	(161.719)	(76.129)	(624.245)	(1,058.486)	(508.533)
Observations	6,833	6,833	6,833	996	996	996
Number of FIPS	2,306	2,306	2,306	358	358	358

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 4: Fixed Effects-Instrumental Variable (FE-IV) Regression Results

	United States			Western States		
VARIABLES	Total Water (1)	Surface Water (2)	Ground Water (3)	Total Water (4)	Surface Water (5)	Ground Water (6)
Insured Crop Acres	0.000	-0.001*	0.001***	0.000	-0.001	0.001
	(0.000)	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)
Average of Maximum Temperature	17.586*	21.905**	-4.318	68.920	122.328*	-53.408
	(8.980)	(10.946)	(6.562)	(50.262)	(68.541)	(45.450)
Square of Maximum Temperature	-0.221	-0.365*	0.145	-0.791	-2.072	1.281
	(0.172)	(0.220)	(0.126)	(1.146)	(1.551)	(1.039)
Average Precipitation	0.701***	1.010***	-0.309	4.956***	4.633***	0.323
	(0.257)	(0.263)	(0.216)	(1.607)	(1.335)	(0.954)
Square of Average Precipitation	-0.003***	-0.004***	0.001	-0.024***	-0.019**	-0.005
	(0.001)	(0.001)	(0.001)	(0.009)	(0.008)	(0.005)
Time Trend	-8.444**	0.281	-8.725***	-44.354***	-37.213**	-7.141
	(3.826)	(4.007)	(2.602)	(15.588)	(14.454)	(8.242)
Constant	-282.235**	-285.210**	2.975	-805.295	-1,400.378*	595.084
	(125.109)	(138.414)	(94.759)	(540.087)	(725.837)	(489.452)
Observations	5,070	5,070	5,070	576	576	576
Number of FIPS	1,841	1,841	1,841	219	219	219

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 5: Fixed Effects-Instrumental Variable (FE-IV) Regression Results

	United States			Western States		
	Total Water	Surface Water	Ground Water	Total Water	Surface Water	Ground Water
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Insured Crop Acres	-0.003**	-0.004**	0.000	-0.001	-0.017	0.015
	(0.002)	(0.002)	(0.001)	(0.049)	(0.319)	(0.299)
Fertilizer Price Index	-9.639**	-8.145**	-1.495	-16.007	-325.590	309.584
	(3.815)	(3.353)	(1.596)	(1,010)	(6,585)	(6,172)
Crop Price Index	325.768***	299.039***	26.729	-201.704	7,585.228	-7,786.933
	(122.237)	(109.779)	(51.238)	(24,365)	(158,714)	(148,858)
Average of Maximum Temperature	-56.989	-32.842	-24.147	-124.423	-3,495.474	3,371.053
	(37.031)	(35.657)	(14.817)	(11,200)	(73,112)	(68,516)
Square of Maximum Temperature	1.001	0.445	0.555**	1.185	54.528	-53.343
	(0.690)	(0.663)	(0.279)	(176.603)	(1,153.840)	(1,081)
Average Precipitation	1.219*	1.313**	-0.094	-1.284	-42.130	40.846
	(0.651)	(0.635)	(0.275)	(140.396)	(912)	(854)
Square of Average Precipitation	-0.005*	-0.006**	0.000	0.002	0.138	-0.135
	(0.003)	(0.003)	(0.001)	(0.463)	(3.004)	(2.813)
Time Trend	387.689**	333.360**	54.329	657.399	12,536.929	-11,879.533
	(156.749)	(138.354)	(65.095)	(38,884)	(253,568)	(237,645)
Constant	457.580	277.918	179.662	2,286.717	38,425.379	-36,138.670
	(386.004)	(394.496)	(148.065)	(122,019)	(796,104)	(745,880)
Observations	4,550	4,550	4,550	555	555	555
Number of FIPS	1,749	1,749	1,749	203	203	203

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1