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Impacts of crop insurance on water withdrawals for irrigation

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ABSTRACT

Agricultural production remains particularly vulnerable to weather fluctuations and extreme events, such as droughts, floods, and heat waves. Crop insurance is a risk management tool developed to mitigate some of this weather risk and protect farmer income in times of poor production. However, crop insurance may have unintended consequences for water resources sustainability, as the vast majority of freshwater withdrawals go to agriculture. The causal impact of crop insurance on water use in agriculture remains poorly understood. Here, we determine the empirical relationship between crop insurance and irrigation water withdrawals in the United States. Importantly, we use an instrumental variables approach to establish causality. Our methodology exploits a major policy change in the crop insurance system – the 1994 Federal Crop Insurance Reform Act – which imposed crop insurance requirements on farmers. We find that a 1% increase in insured crop acreage leads to a 0.223% increase in irrigation withdrawals, with most coming from groundwater aquifers. We identify farmers growing more groundwater-fed cotton as an important mechanism contributing to increased withdrawals. A 1% increase in insured crop acreage leads to a 0.624% increase in cotton acreage, or 95,602 acres. These results demonstrate that crop insurance causally leads to more irrigation withdrawals. More broadly, this work underscores the importance of determining causality in the water-food nexus as we endeavor to achieve global food security and water resources sustainability.

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1. Introduction

Risk in agricultural production is as old as agriculture itself (Mazoyer and Roudart, 2006). Much has been done over the millenia to reduce this risk, including the introduction of new crop varieties, pesticides, herbicides, fertilizer, irrigation systems, and other inputs (Federico, 2008). However, production risk in agriculture is projected to increase as rainfall patterns become more uncertain and flood and drought events occur more frequently with climate change (Lobell et al., 2011b; Parry et al., 2004; Sheffield and Wood, 2008). For this reason, risk management instruments – such as crop insurance – will likely become an increasingly important component of our food system. Crop insurance is one of the main tools for farmers to mitigate the impacts of production fluctuations. Crop insurance takeup has dramatically increased in the United States over the last several decades: in 2014, there were 1.2 million crop insurance policies in the U.S., covering 120 different crops and over 294 million acres (an area larger than Texas and California combined). The total value of agricultural production insured in 2014 was $110 billion (USDA, 2015). Despite its growing importance in the food system, we still do not understand how crop insurance impacts water resources.

Changes in the socio-economic system can impact agriculture as significantly as fluctuations in climate. Agriculture is responsible for approximately 70% of freshwater withdrawals both globally and within the U.S., and is by far the largest consumptive user of freshwater resources (Gleick and Palaniappan, 2010; Postel et al., 1996; Vörösmarty et al., 2000). The agricultural sector faces a number of growing challenges to its current water use. Demands from other water users, such as industry, municipalities, and recreation – as well as environmental flow requirements – are increasing, straining agricultural water resources and water sustainability overall (McDonald et al., 2011). In addition, changes in climate variability and extremes will alter the availability and demand for water resources, making it potentially more difficult for farmers to grow crops as they have done in the past, which threatens food security (Hertel et al., 2010; Lobell et al., 2011a; Schmidhuber and Tubiello, 2007). This makes it imperative to understand how interactions in coupled human and natural systems (Liu et al., 2007) – such as agriculture – impact water resource sustainability.

Insurance products, including crop insurance, exist to provide people the opportunity to pay to be sheltered from financial

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fluctuations. Although crop insurance comes in many forms, its key feature is that it protects farmers against fluctuations in income caused by extreme weather events, pests, or disease. Crop insurance has been shown to lead to riskier farming practices (Cai et al., 2015; Cole et al., 2014; Karlan et al., 2014; Mobarak and Rosenzweig, 2015), with potential implications for food security. It has also been shown that crop insurance increases the number of acres in production (Goodwin et al., 2004) and impacts crop choice (Barnett et al., 2002; Claassen et al., 2016; Deal, 2004; Tronstad and Bool, 2010; Wu, 1999). Additionally, studies have shown that crop insurance changes the amount of chemical inputs used by farmers (Babcock and Hennessy, 1996; Goodwin and Smith, 2003; Goodwin et al., 2004; Smith and Goodwin, 1996; Wu, 1999), although this is currently an area of debate in the literature (Weber et al., 2015). However, despite its importance for food production and environmental sustainability, to our knowledge, no study has considered the implications of crop insurance for water resource use. It is thus critical to determine if crop insurance represents another strain on water demand or helps to enhance the sustainability of water resources.

It is important to understand how crop insurance impacts farmer water use decision-making, particularly because agriculture dramatically impacts water resources sustainability. Theoretically, it is unclear how crop insurance impacts water use in agriculture. By providing a guaranteed level of income in case of crop failure, crop insurance can reduce the farmer's incentive to irrigate. This behavior is known as 'moral hazard' and is undesirable from the insurer's point of view, so insurers typically require that farmers irrigate a 'normal' amount in order to receive insurance payouts. On one hand, this still leaves farmers room to use less water relative to what they would use without insurance, as normal irrigation may not be sufficient to keep crops alive during extreme events. On the other hand, it is possible that insurance requirements will push farmers to irrigate when it is clear that the crop has failed and when, without insurance, they would have stopped watering. Moreover, if more irrigated acres are brought into production when crop insurance is made available, water use may go up. Holding acres fixed, farmers may also switch to more or less water-intensive crops. In areas with upstream and downstream water rights, reduction in use by upstream farmers may be offset by an increase in use by downstream farmers. Finally, because water is also used for non-crop irrigation, a decrease in crop irrigation may be offset by increased irrigation for other purposes. Thus, the net impact of crop insurance on irrigation withdrawals is not clear and requires a careful evaluation of the data.

We focus on the U.S. as a case study because it has one of the most developed crop insurance markets in the world and is a key producer from the point of view of global food security. Specifically, the U.S. produces over 30% of the world's corn and over 50% of the world's soybeans. The U.S. also accounts for large shares of the world export market for several staples: about 60% for corn, 40% for soybeans, 25% for wheat, and 70% for sorghum (USDA, 2013). Because corn and wheat (along with rice) provide about 60% of the world's food energy intake, this makes the U.S. an important contributor to global food security (FAO, 2013). Moreover, data on both crop insurance and water use are available at a high spatial resolution (i.e. county level) in the United States.

To obtain a causal estimate of the impact of crop insurance on irrigation withdrawals, we require an approach that goes beyond statistical techniques that yield only correlational understanding. With this goal in mind, we employ statistical tools to evaluate the causal impact of crop insurance on water resources. Specifically, we use an instrumental variables approach and exploit a major policy change in the crop insurance system – the 1994 Federal Crop Insurance Reform Act – to understand the causal impact of crop insurance on irrigation withdrawals. While the instrumental variables approach is commonly used in economics and related fields (e.g. Acemoglu et al., 2001; Aizer and Doyle, 2015; Goodwin et al., 2004; Levitt, 1996; Weber et al., 2015, among many), to our knowledge it has not been used in water resources research. We explain our methodology in more detail in Section 2. In Section 3, we present our results, including the correlation between crop insurance and irrigation withdrawals, the corresponding causal estimates, and potential mechanisms. We conclude in Section 4.

2. Methods

In this section, we detail our data sources on crop insurance, irrigation withdrawals, and crop acreage. We also explain the instrumental variables (IV) technique for causal inference.

2.1. Data

Data on crop insurance are taken from the Summary of Business Reports (SBR) (SBR, 2015), published by the US Department of Agriculture. SBR data are at the county-year level and cover the years 1981–2013. SBR includes the number of insurance policies purchased, the number of acres insured, total liability, premiums, and indemnity payments. We restrict our sample to counties that appear in the SBR at least once (even if no crop insurance policies were purchased); counties that do not appear in the SBR either have little agriculture or do not have the option to purchase crop insurance.

Our data on water use come from the USGS National Water-Use Information Program (USGS, 2015), which publishes comprehensive estimates of county-level water withdrawals every five years. The data include withdrawals for irrigation by surface and groundwater source, as well as the total number of irrigated acres. In this study, we use irrigation withdrawals in the years 1990 and 1995. In these years, USGS irrigation water withdrawal data include all water artificially applied to crop and pasture lands, as well as to recreational lands, such as parks and golf courses (Solley et al., 1998). In 2005 and 2010, USGS reported crop irrigation withdrawals separately from total irrigation withdrawals. During these years, the median (average) county in our sample used 93% (78%) of its total irrigation withdrawals for crop irrigation.

USGS provides the only comprehensive database of water use across sectors and water sources for the entire United States. However, USGS water use data are not ideal because they are often estimated rather than measured directly. USGS irrigation values can be derived from reported withdrawals or be approximations that are based on cropped area and crop water requirements. In addition, if insufficient data are available in a particular census year, then information from previous years can be used (USGS, 2015). Unfortunately, it is not clear which states or counties measure or estimate their withdrawals. Because some of the withdrawals are approximated, our estimates should be viewed as lower bounds, because we would expect no relationship between crop insurance and solely approximated withdrawal data.

Data on crop acreage come from the National Agricultural Statistics Service (NASS) (NASS, 2015), which publishes annual county-level estimates of acres harvested for various crops. In some cases, NASS also provides data for acres planted. We would prefer to use information on acres planted in this analysis, as this more directly captures farmers' *ex ante* decision-making than does acres harvested. Unfortunately, the acres planted variable is very sparsely populated so we use the acres harvested variable instead. A key limitation of this substitution is that harvesting decisions may be affected by irrigation decisions, making the interpretation of results less straightforward. In addition, planted and harvested acreage can and have diverged substantially over time, as evidenced by U.S. cotton acreage planted and harvested (NASS, 2015).

2.2. Causal inference with instrumental variables

We are interested in the causal relationship between crop insurance uptake and water use for irrigation, which can be represented by the following regression equation:

$$\Delta WaterUse_c = \beta \Delta Ins_c + \mathbf{X}_c'\gamma + \upsilon_{c,1995}.$$

The variable $\Delta WaterUse_c$ is the change in the log amount of water withdrawn for irrigation between 1990 and 1995 in county c, ΔIns_c is the change in the log of insured acres in the county, and $\mathbf{X}_c$ is a set of control variables.

Many empirical studies utilize an ordinary least squares (OLS) regression approach, which estimates the partial correlation between two variables of interest, to explore the relationships between them. In many cases, simply knowing the correlation between variables is insufficient for understanding their causal relationship, even with carefully chosen controls. For example, there may be reverse causality or an unobserved confounding factor that affects both outcomes. In the case of crop insurance and water use, farmers may be choosing how much insurance to take out based on their expected water use (reverse causality). Furthermore, unobservable (to the researcher) risk factors, such as a drought, may be affecting both crop insurance and irrigation decisions. Thus, crop insurance is an 'endogenous' rather than a truly independent ('exogenous') variable. In cases where endogeneity is present, simply looking at the correlation between the two variables may be misleading for causal interpretation.

To establish causality, we use an 'instrumental variables' (IV) or 'two-stage least squares' approach (Angrist and Pischke, 2009; Cameron and Trivedi, 2005; Wooldridge, 2012). For this approach to work, a variable must be identified that is (1) strongly correlated with crop insurance coverage and (2) uncorrelated with any unobservable determinants of the outcome of interest, in this case irrigation water use, except through insurance coverage. Such a variable is known as an 'instrument'.

In the 'first stage' of an instrumental variables estimation, the researcher isolates the variation in the endogenous variable that is driven by another variable that is only related to the ultimate outcome of interest through the endogenous variable. In the 'second stage', the researcher uses the predicted value of the endogenous variable from the first stage as the independent variable to obtain a causal estimate. Because the first stage is estimated rather than measured, calculation of standard errors in the second stage must take uncertainty of the first stage into account. Here, we use the built-in instrumental variables package for Stata, which automatically performs this standard error correction.

To construct an instrument for crop insurance coverage, we use variation created by the 1994 Federal Crop Insurance Reform Act, which significantly raised premium subsidies for some products and made catastrophic insurance coverage mandatory for producers who participated in any USDA farm program, which is the vast majority of farmers.

The 1994 Act had a large and immediate effect on insurance coverage. Fig. 1 shows the total number of insured acres in the United States for the years 1981–2010. Prior to 1989, crop insurance takeup was relatively low, hovering around 50 million acres per year. Between 1988 and 1989 the number of acres covered almost doubled, as premium subsidies were made more generous. Between 1994 and 1995, the number of insured acres more than doubled as the insurance requirement was put in place and premium subsidies were made even more generous. In absolute terms, the 1994–1995 increase in crop insurance dwarfs the 1988–1989 increase as more than 100 million acres were newly insured in a single year. The percent of eligible acreage enrolled in crop insurance skyrocketed to 80% in 1995 (Coble, 2000).

In the next year, Congress eliminated the requirement, creating a de facto natural experiment (Glauber, 2004). However, the subsidies were not decreased, so insurance coverage remained at higher levels than in previous years. As is evident from Fig 1, the 1994–1995 policy change is the most drastic in the recent history of the U.S. crop insurance program. It is also a plausibly exogenous source of variation in crop insurance coverage, so we focus on this policy change in our analysis. Importantly, while the policy undoubtedly affected insurance takeup, it is unlikely to be related to other determinants of water use.

To exploit this policy change in a county-level regression analysis, we use the fact that counties that already had high insurance coverage were less affected than counties where coverage was low. Thus, insurance coverage in 1994 can be used to predict future changes in coverage, with higher 1994 insurance coverage corresponding to smaller changes. Specifically, we predict the amount of insurance takeup that is driven by the 1994 policy change by estimating the following first stage equation:

$$\Delta Ins_c = \gamma Insurance_{c,1994} + \sum_{t=1990}^{1994} \theta_t Growth_{c,t} + \varepsilon_{c,1995},$$

where the subscripts c and t index the county and year, respectively. The outcome variable, $\Delta Ins_c = Insurance_{c,1995} - Insurance_{c,1990}$ is the change in the log acres insured in the county between 1990 and 1995. Our instrument is $Insurance_{c,\,1994}$, the log of insured acres in county c in year 1994, one year before the policy change went into effect. Because counties that already had high insurance coverage were not as impacted by the new insurance requirements, we expect γ to be negative.

In order for crop insurance coverage in 1994 to be a good instrument in our setting, it must be strongly correlated with growth in crop insurance coverage between 1990–1995 but uncorrelated with other determinants of irrigation withdrawals. While the first requirement is directly testable, the second (known as the 'exclusion restriction') is not. The most plausible threat to the validity of our instrument is that counties where agriculture is growing fastest may have both higher crop insurance coverage in 1994 and faster growth in water use as a result. In that case, our instrument would violate the exclusion restriction and our estimates would not reflect the causal effect of crop insurance on water use. We include various growth controls to determine whether this is a serious concern. Our preferred approach is to control for a set of variables $Growth_{c,\,t}$, which are defined as the change in acres insured between years t and $t-1$, expressed as a percent of acres insured in year $t-1$. These variables flexibly control for year-to-year growth in insurance coverage and increase the likelihood that the variation in crop insurance is being driven by the 1994 policy change rather than by differential growth rates in agriculture over time. Intuitively, if the addition of these controls has a large effect on the estimates, then the likelihood of unobservables confounding our results is higher. In the next section, we also probe the robustness of our results to the inclusion of other control variables related to economic and agricultural growth.

The second stage of the estimation takes the predicted values for ΔIns_c and uses those as the independent variable:

$$\Delta WaterUse_c = \beta_1 \widehat{\Delta Ins_c} + \sum_{t=1990}^{1994} \delta_t Growth_{c,t} + \upsilon_{c,1995}$$

$$\Delta CropArea_c = \beta_2 \widehat{\Delta Ins_c} + \sum_{t=1990}^{1994} \delta_t Growth_{c,t} + \epsilon_{c,1995}$$

where $\Delta WaterUse_c$ is the change in the log amount of water withdrawn for irrigation between 1990 and 1995, and $\Delta CropArea_c$ is the corresponding change in the log harvested area of a crop. Note that 5-year changes are considered because water withdrawal

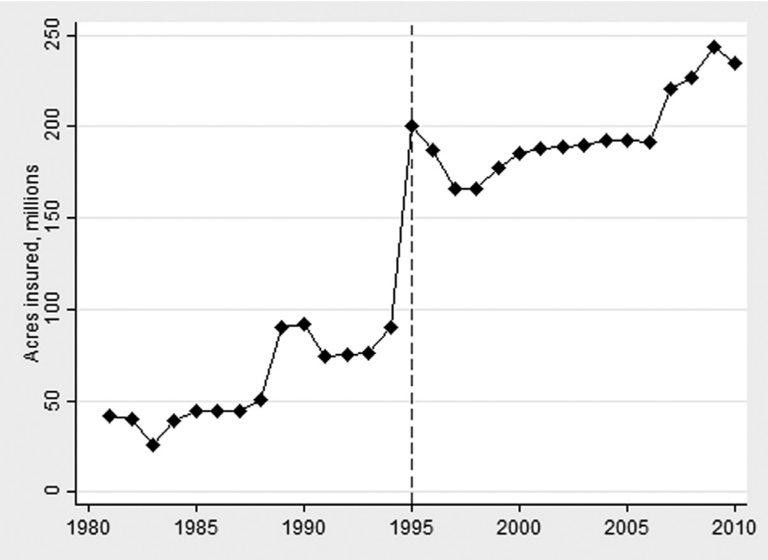

Fig. 1. Total number of insured acres in the United States, 1981–2010, millions.

Table 1
The effect of crop insurance on water withdrawals, OLS versus instrumental variables.

	Change in log water withdrawals		Change in log acres insured
	OLS	IV	First stage
5-year change in log acres insured	0.051** (0.024)	0.223*** (0.069)	
Log acres insured in 1994			-0.145*** (0.012)
Observations	2007	2007	2007
First stage F-statistic		149	149

1. Robust standard errors in parentheses. 2. *** denotes significance at the 1% level. ** denotes significance at the 5% level. 3. Dependent variable indicated at the top of the columns. 4. All regressions include each of the year-to-year changes in insured acres (in logs) over 1989–1994 as controls.

data is provided at this frequency (USGS, 2015). The independent variable $\widehat{\Delta Ins_c}$ is the predicted change in the log of insured acres in the county. As in the first stage, we include flexible controls for year-to-year growth in coverage in years other than 1994–1995. The coefficient β_1 estimates how total water use changes as insurance takeup increases. The coefficient β_2 estimates how crop harvested area changes as insurance takeup increases. These estimates enable us to understand whether and to what extent water withdrawals for irrigation increased or decreased as a direct results of increased penetration of crop insurance.

3. Results and discussion

Here, we present and discuss results on the relationship between crop insurance and irrigation withdrawals. First, we compare the correlational (OLS) and causal (IV) estimates of the relationship between changes in insured acreage and irrigation withdrawals. Then, we probe the robustness of our IV estimates and examine a few potential mechanisms for the impact of crop insurance on irrigation withdrawals. Note that our estimates capture the marginal effect of crop insurance. If the relationship between crop insurance and irrigation withdrawals is non-linear, as is likely to be the case, the marginal effect of crop insurance is not constant and regression point estimates cannot be used to approximate the aggregate impact of the 1994 policy mandate.

3.1. Main results

Table 1 shows the OLS and IV estimates of the relationship between crop insurance coverage and water use for irrigation. OLS estimates reveal that there is a statistically significant and positive relationship between 5-year changes in log irrigation withdrawals and 5-year changes in log acres insured in a county (refer to column 1 of Table 1). Specifically, a 1% increase in insured acreage is associated with a 0.051% increase in contemporaneous irrigation water withdrawals, suggesting that crop insurance increases water use.

However, simply looking at the correlation between changes in water use and insurance coverage is uninformative about the causal relationship between the variables. In column 1 of Table 1 water use is treated as the dependent variable. But, farmers may choose how much insurance to take out based on their expected water use, implying that causality also runs in the opposite direction. It could also be that when farmers anticipate a risky growing season, they increase both insurance coverage and irrigation withdrawals. For scientific understanding and policy purposes, we are most interested in how the take-up of crop insurance causally impacts water use in agriculture.

IV results, which enable us to identify the causal impact of crop insurance on water use, are provided in column 2 of Table 1. The coefficient of interest (β_1; refer to Section 2) is positive and statistically significant at the 1% level. The results indicate that a 1% increase in insured acreage leads to a 0.223% increase in water withdrawals. Significantly, this relationship has a causal interpretation. It is also about four times larger than the corresponding OLS estimate, suggesting considerable bias in the latter.

Next, we check the strength and reasonableness of the first stage (refer to columns 3 of Table 1). As expected, the estimated coefficient is negative and highly statistically significant. The point estimate indicates that counties with less insured acres in 1994

Table 2
Robustness of instrumental variables estimates.

	(1)	(2)	(3)	(4)	(5)
Panel A: change in log water withdrawals (second stage)					
5-year change in log acres insured	0.252***	0.184***	0.223***	0.335***	0.179***
	(0.086)	(0.054)	(0.069)	(0.118)	(0.059)
Observations	2,095	2,072	2,007	975	2,015
Panel B: change in log acres insured (first stage)					
Log acres insured in 1994	−0.115***	−0.212***	−0.145***	−0.144***	
	(0.012)	(0.011)	(0.012)	(0.017)	
Log acres insured in 1993					−0.176***
					(0.012)
Observations	2,095	2,072	2,007	975	2,015
First stage F-statistic	90	352	149	75	232
Controls	None	County chars.	Growth in insured acres	Growth in insured acres	Growth in insured acres
Sample	All	All	All	> 50% crop irr.	All
Estimator	2SLS	2SLS	LIML	2SLS	2SLS
Year used for instrument	1994	1994	1994	1994	1993

1. Robust standard errors in parentheses. 2. *** denotes significance at the 1% level. 3. Dependent variable indicated in the panel title. 4. ‘County chars." growth controls regression includes the change in insured acres, population, number of farm proprietors, and per-capita income (in logs), as well as changes in farm income deciles over 1990–1994 as controls. "Growth in insured acres" controls include each of the year-to-year changes in insured acres (in logs) over 1989–1994 as controls.

saw more crop insurance uptake in 1995 than did those that already had relatively high levels of coverage. Importantly, our instrument is very strong. The Kleibergen-Paap statistic rk Wald F statistic (‘First stage F-statistic’ reported in Table 1) is almost 150, well above the rule-of-thumb threshold of 10 for weak instruments. We also pass the Anderson-Rubin test (for our main results, the F is 10.15, *p*-value is 0.0015), although it should be noted that the A-R test is not efficient in cases where the instrument is strong, as is the case here. A closely related statistic based on a Lagrange Multiplier test (the Stock-Wright S statistic) produces similar results. Similarly, the Conditional Likelihood Ratio test p-value is 0.0019. Finally, we have also used LIML instead of 2SLS, with little change to the results (refer to column 4 of Table 2).

In Table 2, we probe the robustness of our IV estimates to alternative specifications. Panel A shows the second stage estimates, while Panel B shows the first stage. First, we omit the growth in insured acres controls from the regression (column 1). The fact that these growth controls do not make a significant difference makes us more confident that we have truly isolated the effect of the policy change. Then, instead of controlling for growth in log acres insured in each year between 1989 and 1994, we control for 1990–1994 changes in the following variables (all in logs): the number of farm proprietors, population, per capita income, and insured acres. We also control for the change in the county's farm income decile between 1990–1994 (column 2). These controls are meant to capture changes in a county's economy that may be correlated with both insurance and irrigation decisions. Next, we use limited information maximum likelihood (LIML) estimation instead of two-stage least squares (2SLS) estimation because the former is robust to the presence of weak instruments (column 3). Finally, we restrict our sample to counties where more than half the irrigation withdrawals were used for crops in 2005 and 2010 (column 4). It is clear from Table 2 that our results are very robust to all these modifications.

Additionally, we instrument for changes in acres insured using 1993 crop insurance coverage, controlling for coverage growth in each year between 1989 and 1993 (column 5 of Table 2). We do this because a non-trivial share of the counties in our sample experienced a flood or drought in 1993 (Lott, 1994; Pal and Eltahir, 2002; Trenberth and Guillemot, 1996). The occurrence of these extreme events could have affected both insurance uptake (either because of disaster aid requirements or because farmers' risk perceptions were affected) and irrigation. In that case, our IV estimates could be biased. However, because 1993 crop insurance decisions had to be made before March 15th of that year, they predate the flood events. We find similar first and second stages as when we use 1994 coverage (refer to Table 2 column 5), suggesting that the 1993 extreme events are not biasing our estimates.

Table 3
Log-log second stage, change in log water withdrawals by source.

	Total	Surface	Groundwater
Log acres insured	0.223***	0.148*	0.275***
	(0.069)	(0.081)	(0.076)
Growth controls	Y	Y	Y
F-Stat	148.71	146.81	136.01
Observations	2,007	1,649	1,580

1. Robust standard errors in parentheses. 2. *** denotes significance at the 1% level. * denotes significance at the 10% level. 3. Dependent variable is 5-year change in log water withdrawal by type. Water type indicated at the top of the columns. 4. Growth controls includes each of the year-to-year changes in insured acres (in logs) over 1989–1994 as controls.

Next, we estimate the effect of crop insurance on water withdrawals by source of water (Table 3). From Table 3, it is clear that groundwater withdrawals comprise the majority of the increase in total water withdrawals, at least in relative terms. The coefficient on surface water withdrawals is 0.148 (statistically significant at the 10% level), indicating that a 1% increase in insured acres leads to a 0.148% increase in surface withdrawals. The coefficient for groundwater withdrawals is 0.275 (statistically significant at the 1% level), indicating that a 1% increase in insured acres leads to a 0.275% increase in groundwater withdrawals.

For surface water, the average withdrawal volume is 10,895.55 [Mgal] across 2,836 observations in 1995. Our coefficient for the impact of a 1% increase in insured acres on surface irrigation is 0.148. So, we multiply 2,836*10,895.55*0.00148 to get that a 1% increase in insured acres leads to an increase in surface water use of 45,732 Mgal. To convert to km^3 we multiply 45,732 Mgal by $3.78541178*10^{-6}$. Thus, our findings imply that a 1% increase in insured acres leads to an increase of 0.17 km^3 in surface water use. For groundwater, the average withdrawal volume is 6,305.13 [Mgal] across 2,836 observations in 1995. Our coefficient for the impact of a 1% increase in insured acres on surface irrigation is 0.275. We calculate that a 1% increase in insured acres leads to an increase of 49,174 Mgal or 0.19 km^3 in groundwater use.

Table 4
Log-log second stage, change in log area.

	Harvested	Irrigated
Log acres insured	−0.214*** (0.042)	−0.019 (0.063)
Growth controls	Y	Y
Observations	2,087	2,072
F-Stat	158.22	159.16

1. Robust standard errors in parentheses. 2. *** denotes significance at the 1% level. 3. Dependent variable is 5-year change in acres harvested or acres irrigated, as indicated at the top of the columns. 4. Growth controls includes each of the year-to-year changes in insured acres (in logs) over 1989–1994 as controls.

Table 5
Second stage, change in fraction [%] harvested area by crop.

	Corn	Cotton	Rice	Soy	Wheat
Log acres insured	0.047*** (0.019)	0.134*** (0.038)	0.032 (0.020)	-0.035*** (0.009)	0.027*** (0.009)
Growth controls	Y	Y	Y	Y	Y
F-Stat	420.72	66.02	7.12	337.83	201.47
Observations	1,705	452	106	1,368	1,689

1. Robust standard errors in parentheses. 2. *** denotes significance at the 1% level. 3. Dependent variable is 5-year change in total harvested share of different crops, as indicated at the top of the columns. 4. Growth controls includes each of the year-to-year changes in insured acres (in logs) over 1989–1994 as controls.

Table 6
Log-log second stage, change in log harvested area by crop.

	Corn	Cotton	Rice	Soy	Wheat
Log acres insured	−0.162*** (0.030)	0.624*** (0.185)	−0.061 (0.096)	−0.301*** (0.043)	0.100** (0.045)
Growth controls	Y	Y	Y	Y	Y
Observations	1,705	452	106	1,368	1,689
F-Stat	420.72	66.02	7.12	337.83	201.47

1. Robust standard errors in parentheses. 2. *** denotes significance at the 1% level. ** denotes significance at the 5% level. 3. Dependent variable is 5-year change in acres harvested of different crops, as indicated at the top of the columns. 4. Growth controls includes each of the year-to-year changes in insured acres (in logs) over 1989–1994 as controls.

Table 7
OLS, change in log groundwater withdrawals, 1990–1995.

	Corn	Cotton	Rice	Soy	Wheat
Change in log acres harvested, 1990–1995	−0.294*** (0.058)	0.277*** (0.055)	0.243 (0.231)	−0.179*** (0.059)	−0.070 (0.049)
Growth controls	No	No	No	No	No
Observations	1,273	370	98	971	1,314
R^2	0.020	0.065	0.011	0.009	0.002

1. Robust standard errors in parentheses. 2. *** denotes significance at the 1% level. 3. Dependent variable is 5-year change in log groundwater withdrawals. 4. Independent variable is 5-year change in log acres harvested of different crops, as indicated at the top of the columns.

3.2. Why does crop insurance increase irrigation?

Why do irrigations withdrawals increase as farmers purchase more crop insurance? Here, we explore several explanations. First, farmers may expand total irrigated crop acreage, leading to additional irrigation withdrawals. Second, holding crop acreage fixed, farmers may change their crop mix, potentially switching to more water-intensive crops. Third, holding crop type constant, farmers may irrigate more per unit area in order to meet the insurance policy requirements or due to farm cost effects.

3.2.1. Total crop acreage

Crop insurance may lead farmers to expand crop acreage, which could lead to more irrigation withdrawals. To examine this, we look at data on irrigated area as reported in the USGS database. We also examine harvested area data as provided by NASS. Ideally, we would be able to examine the causal impact to planted area, as this is the variable that most accurately captures farmer planting decisions. However, we examine harvested area rather than planted area due to the lack of planted area data availability. Planted area is a variable provided by NASS, but there are very few observations available for crop planted area, unfortunately (NASS, 2015).

Table 4 presents second-stage results for log harvested area and log irrigated area. The coefficient on log total harvested area is statistically significant at the 1% level but negative (−0.214), indicating that the total harvested crop area actually decreases as a result of crop insurance. The coefficient on log irrigated area is also negative, but it is not statistically significant (−0.019). So, it is unlikely that the increased irrigation withdrawals are due to expansions in crop area. However, our results on crop acreage must be interpreted with caution, for the reasons highlighted above.

3.2.2. Crop mix

Crop insurance may lead farmers to change their crop mix planting decisions (Cole et al., 2014; Wu, 1999), potentially switching to more water-intensive crops. To explore this explanation, we evaluate the causal impact of crop insurance on the harvested area of staple crops (i.e. corn, cotton, rice, soy, and wheat) in the United States. Table 5 presents second-stage results for the change in the fraction [%] of harvested area by crop. The share of crop acreage devoted to cotton, a water-intensive crop, increases following the 1994 policy. Corn (0.047***) and wheat (0.027***) also increase their share of crop acreage following the policy change. However, cotton increases its share of crop acreage the most (0.134***), while rice exhibits a positive, but statistically insignificant change (0.032), and soy shows a decline in its share (−0.035***).

Because total crop acreage decreases, it is useful to look at the harvested area of each crop in addition to its share of the total harvested area. Table 6 presents second-stage results for crop harvested area as the outcome variable. The results are statistically significant for all crops, except for rice. The harvested area of corn and soy decreases with insurance up-take (corn coefficient = −0.162, corresponding to −87,950 corn acres; soy coefficient = −0.301, corresponding to −154,472 soy acres). However, the harvested area of cotton and wheat increases, indicating that the increase in water withdrawals are likely attributable to these crops. A 1% increase in crop insurance leads to a 0.100% increase in wheat acreage, corresponding to 57,818 acres; and a 0.624% increase in cotton acreage, or 95,602 acres. So, crop insurance leads to a greater impact – in both relative and level terms – to cotton acreage than it does for wheat.

Cotton is a water-intensive crop and is responsible for the largest share of the water footprint of traded commodities (Hoekstra and Mekonnen, 2012). For this reason, it is likely that the increases in cotton acreage are contributing to increased irrigation withdrawals, particularly from groundwater sources. Maps of spatial changes in cotton production and corresponding groundwater withdrawal changes from 1990 to 1995 are presented in Fig. 2. Regression results between changes in crop acreage and groundwater withdrawals are provided in Table 7. In Table 7, note that cotton is the only crop for which the coefficient is positive and statistically significant (the coefficient = 0.277 and is significant at the 1% level), indicating that counties that increased their log cotton acreage also increased their log groundwater withdrawals from 1990 to 1995. Table 7 lends further evidence that farmers switching to water-intensive and groundwater-fed cotton is one channel via which crop insurance leads to increased irrigation withdrawals.

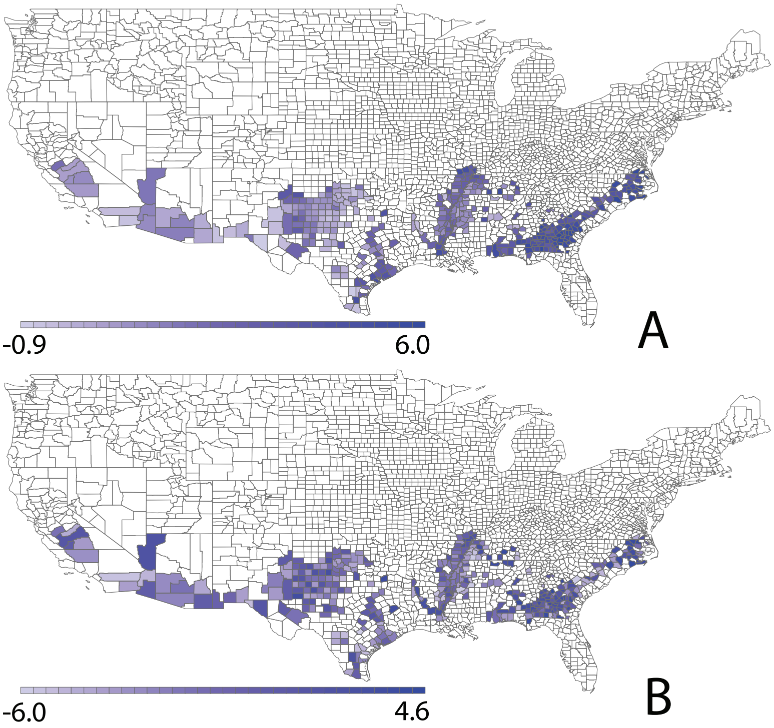

Fig. 2. Cotton acreage and groundwater withdrawal maps of the United States. A) Change in log cotton acres harvested from 1990 to 1995. B) Change in log groundwater withdrawals for irrigation in counties that produce cotton from 1990 to 1995. Note that maps illustrate changes around the 1995 insurance policy mandate. The change in log cotton acres harvested is associated with a statistically significant positive relationship (regression coefficient = 0.277***; refer to Table 7) with the change in groundwater withdrawals.

Table 8
Log-log second stage, change in irrigation withdrawals per area irrigated.

	Total	Surface	Groundwater
Log acres insured	0.223*** (0.059)	0.095 (0.073)	0.399*** (0.071)
Growth controls	Y	Y	Y
F-Stat	151.35	146.40	137.39
Observations	1,990	1,641	1,571

1. Robust standard errors in parentheses. 2. *** denotes significance at the 1% level. 3. Dependent variable is 5-year change in water use per irrigated acre by water type, as indicated at the top of the columns. 4. Growth controls includes each of the year-to-year changes in insured acres (in logs) over 1989–1994 as controls.

3.2.3. *Irrigation per unit area*

Crop insurance may lead farmers to apply more water per unit area, reducing their water use efficiency. This could happen if insurance reduces farmer total farm expenditures, inducing them to spend more on irrigation charges (or the electricity for groundwater pumping). It is also possible that insurance contract design leads to additional water withdrawals holding crop type and acreage fixed. The USDA's Federal Crop Insurance Corporation (FCIC) typically requires that farmers irrigate 'normal' quantities of water in order to receive insurance payouts in the event of a crop loss (FCIC, 2006). Farmers may be risk-averse and make a conservative decision to water their crops – even when it is clear the crop has failed – in order to guarantee that they receive their insurance payment.

Table 8 presents second-stage results for the change in log irrigation withdrawals per log irrigated acreage. The coefficients in this table reveal that farmers apply more irrigation water per unit of irrigated area following the policy change. Consistent with Table 3, most of the increased irrigation is from groundwater sources. Unfortunately, we are not able to determine more precisely why farmers apply more water per unit land at this time due to a lack of necessary data. They could be either responding to the costs of farming or to the crop insurance policy requirements, or both.

4. Concluding remarks

It is imperative to understand interactions between risk management and resource sustainability in agriculture. This is particularly true if we want to understand opportunities to improve food security under an uncertain climate future. In this paper we employed instrumental variables statistical techniques to determine the causal impact of crop insurance on irrigation in the United States. This is the first study, to our knowledge, that employs methods of causal inference to determine the implications of crop insurance policies for water resources sustainability. As such, it is a critical first step to enable scientific and policy communities to understand drivers of food and water security.

We demonstrate that crop insurance causally increases irrigation. A 1% increase in insured crop acreage leads to a 0.223% increase in irrigation withdrawals. The impact of crop insurance on water withdrawals is much larger than that suggested by an ordinary least squares correlation (0.054%). The impact is more pronounced for groundwater withdrawals: a 1% increase in insured acreage leads to a 0.275% increase in groundwater withdrawals, or 0.19 km^3. We identify the crop switching decision as one important channel through which crop insurance increases irrigation withdrawals. Importantly, we show that insurance uptake causally increases the amount of cotton acreage, which is a water-intensive crop. Specifically, a 1% increase in insured acreage leads to a 0.624% increase in cotton acreage, or 95,602 acres. Crop insurance also increases the volume of irrigation water applied per unit irrigated area, although the underlying reason for this requires further research.

The fundamental design of crop insurance in the U.S. has not changed for the past 20 years, making it likely that our results remain valid for the U.S. and other countries today. There have been calls to reform the U.S. crop insurance system due to the financial burden placed on the American taxpayer (Babcock, 2013). This paper contributes to the policy debate by highlighting that crop insurance policies negatively impact water resources sustainability in the United States. One unintended consequence of the current risk management system has been to contribute to the overexploitation of groundwater reserves, which are currently undervalued but likely to become increasingly important for food security under an uncertain climate future. This study also highlights the importance of continuing to improve national water use data in the United States for scientific and policy insight.

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