Groundwater Pumping Restriction and Expenditures on Crop Insurance

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Abstract

Resource managers increasingly employ extraction limits to address the overextraction of shared resources, but researchers have not explored how these limits affect production risk. In this paper, we investigate how local groundwater quantity restrictions (GQRs) in the Ogallala Aquifer Region affect the cost of crop insurance, a cornerstone of agricultural risk management. We exploit variation in timing of GQR implementation from counties in the Region from 2002 to 2016 to test if GQRs affect insurance prices and trigger shifts in farmer coverage decisions. We find that QCRs increase overall insurance costs, with much of the burden falling on the federal government through increased subsidy dollars paid. These results highlight important interactions between conservation and risk management policies that influence both farm-level decisions and public expenditures.

Keywords: Crop Insurance, Water Conservation, Environmental Federalism, Agricultural Risk Management

1. Introduction

Groundwater supports irrigated agriculture across the world by providing nearly half of irrigation water for food production (Siebert et al 2010). The common-pool nature of groundwater leads to inefficient rates of depletion (Auschbach-Hertig & Gleeson, 2012, de Frutos Cachorro et. al 2021), with important implications for food security and markets (Perez et al. 2024). To prevent overexploitation, regulators have implemented groundwater quantity restrictions (GQRs), particularly at the local level (Wang, Park, & Jin, 2015). GQRs alleviate common-pool resource market failures in groundwater allocation (Koundouri, 2004) by placing a limit on the amount of groundwater that farmers can use within a given period (Hrozencik et al., 2024). This leads to higher groundwater levels over time but also increases production risks (Lejars et al., 2012). Previous research on GQRs has explored the impacts of GQRs on irrigation (Drysdale & Hendricks, 2018, Smith et. al 2017) and land values (Ifft, Bigelow, & Savage, 2018, Edwards, 2016), but impacts to risk management expenditures remain unexplored.

In the United States (US), crop insurance is a prominent risk management tool that facilitates investment and stability in food production by protecting farmers from yield losses and price volatility (Coble & Barnett, 2013). Through the Federal Crop Insurance Program (FCIP), the US government spends an average of $3.7 billion per year on crop insurance subsidies (USDA-RMA, 2022). Sloggy et. al (2025) and Deryugina & Konar (2017) find that crop insurance policies influence groundwater use, establishing a connection between water use and risk management. While water supply requirements for irrigated insurance (USDA, 2021) could limit impacts to yield risks, the impact of GQRs on insurance expenditures depends on how producers and policymakers respond to the change in water access.

In this paper, we estimate the impact of local GQRs on federal agricultural risk management expenditures. First, we estimate how GQRs impact the insurance price that producers pay (defined as the premium paid per covered value). Next, we test the margins along which agricultural producers respond to new crop insurance prices. Producers can respond along the extensive margin by changing the number of acres insured, and/or along the intensive margin by adjusting the coverage level of the acres already insured. Finally, we ask how GQRs affect total crop insurance expenditures and how those expenditures are split between agricultural producers (through increased insurance premiums) and the federal government (through increased subsidy payments).

Quantifying the impact of GQRs on risk management expenditures informs the design of both natural resource conservation and insurance policies. It also provides insights for insurers, who may adjust pricing or subsidies in response to GQRs while considering how insurance expenditures influence groundwater use. For natural resource managers, recognizing these interactions between policies can help better account for overall program costs, inform optimal

pumping limits, and highlight potential benefits of policy flexibility. If GQRs increase insurance expenditures, that could place additional financial pressure on agricultural producers that rely on irrigation. Higher crop insurance prices may also affect how agricultural producers choose to use their land, encouraging shifts toward less water-intensive crops (Deryugina & Konar, 2017, Ghosh, Miao, & Malikov, 2021) or even reducing cultivated acreage (Goodwin, Vandaveer, & Deal, 2001). Observed changes in water use after policy changes (e.g., the impact of GQRs on water use in western Kansas (Drysdale & Hendricks, 2018)) may reflect the impacts of both conservation policies and changes in insurance expenditures. These potential changes highlight the need for researchers and policymakers to consider how resource conservation policies interact with risk management tools.

We leverage a natural experiment in which local governments enacted GQRs at different times across resource management districts in the Ogallala Aquifer region of Kansas & Nebraska. We merge information on the timing of GQR implementation with county-level data from the USDA on insurance rates under the FCIP. We also use the Risk Management Agency's (RMA's) Summary of Business (SOB) Reports to include data on county-level values of subsidy, liability, producer premium paid, insured acreage, and coverage levels, focusing on outcomes for irrigated corn producers. Our study focuses on irrigated corn producers because corn production is an economically valuable crop in our study region (Guru & Horne, 2024), representing 39% of insured crop acreage in the study area. We use our dataset to test if GQRs change crop insurance expenditures for producers. We then test for changes in coverage decisions and explore policy incidence by estimating how the government and agricultural producers share impacts to risk management expenditures.

We find that from 2002 to 2016, GQRs increase corn producers' crop insurance price per unit of insured liability by $1.7 for every $100 of liability purchased, representing 35 percent of the mean insurance base price. As prices increase, agricultural producers respond by shifting to policies with lower coverage levels. Although lower coverage levels are cheaper relative to higher coverage levels, we find that the overall increase in insurance prices across all coverage levels is enough to increase total insurance expenditures. We find that implementing a GQR on all irrigated corn acres in a county increases annual insurance expenditures by 48% from an average of $2.2 million per year. Lower subsidy rates at lower coverage levels imply that the federal government bears a larger share of the increased insurance expenditures. Consistent with this, we find that subsidies paid per county increase by 84% while premiums paid by agricultural producers increase by just 27%.

This paper builds on four areas of existing research related to GQRs and crop insurance. First, a growing body of work explores how conservation policies influence water use, land values, and economic returns in agriculture. Drysdale & Hendricks (2018) find that GQRs reduce irrigation in

resource districts and Smith et al. (2017) show that local groundwater price interventions decrease groundwater withdrawals. Despite this, Ifft, Bigelow, & Savage (2018) report no discernible impact of GQRs on farmland values. Steiner et al. (2021) find that a GQR policy in Kansas had little impact on farmer incomes even while farmers exceeded conservation targets. Gisser & Sanchez (1980) and Burnett & Wada (2014) assess the economic efficiency and value of groundwater management, with the former developing a model that suggests minimal impact on farmer welfare and the latter finding that groundwater recharge strategies generate significant economic returns. While these studies provide key insights into the agricultural effects of groundwater policies, they do not consider how conservation measures might alter risk management costs.

Another relevant body of research examines the determinants of crop insurance pricing and the impacts of insurance subsidies paid by the federal government. Woodard (2014) finds that the sample period used to assess weather variability in FCIP rate-making introduces bias. Woodard & Verteramo-Chiu (2017) show that the government's failure to account for soil information reduces the efficiency of the FCIP. Goodwin & Smith (2013) examine how the FCIP's public-private partnership affects taxpayer-funded subsidies and how congressional Farm Bills have influenced these payments over time. Other research has focused on how changes in insurance subsidies affect agricultural risk management. O'Donoghue (2014) finds that increased subsidies lead to higher crop insurance policy coverage levels and modest increases in insured acreage. Ghosh, Miao, & Malikov (2021) find that these higher subsidy payments lead to larger groundwater withdrawals for irrigation.

A third area of relevant research involves overlapping regulations from federal, state, and local levels (e.g., Goulder & Stavins, 2011). Though some studies have placed overlapping regulatory structures into the context of federalism (e.g., Revesz, 2001), others have argued that they are instead a set of second-best policies (e.g., Bennear & Stavins, 2007). In the case of overlapping regulations, federal level regulations often set a baseline, and state, regional, or local level regulations are stricter (Goulder & Stavins, 2011). Other authors have argued that using principles of federalism in regulating environmental issues can be beneficial and have called for research into ecological federalism (Sims et al., 2023). Many studies on this topic examine policies that directly regulate the same activity, for instance car emissions (Carlson, 2003, Leach et al., 2021); however, fewer studies look at overlapping regulations with separate targets that affect the same system, such as the one studied here. Though federalism is often associated with policy in the United States, this topic has also been examined in China (Teets et al., 2021). This topic is particularly important for water management, where resources span many states and include decision makers at the federal, state, and local levels (Frankel et al., 2024). However, there is a gap in this area when looking at policies enacted at different levels of governance to regulate different aspects of the same system.

Finally, a fourth body of research on hydro-economic modeling underscores the welfare benefits of coordinated groundwater management, especially when accounting for factors like soil characteristics, well capacity, and spatial externalities (Hronzencik et al., 2017, Guilfoos et al., 2013, Guilfoos & Merrill, 2018). Recent advances have integrated economic, agronomic, and hydrologic models to assess conservation strategies (Rouhi Rad, Araya, & Zambreski, 2020), but these models often exclude key tools for managing risk, such as crop insurance.

We contribute to the agricultural and natural resource economics literature by integrating insights from applied econometrics to better understand insurance pricing and federal policy responses to local changes in natural resource access. We are the first to estimate how GQRs affect crop insurance expenditures and to explore the incidence of changes in these expenditures. Our results suggest that federal policy may alleviate the local expenditures of resource policies. Additionally, insurance prices can play a role in groundwater use and availability (Sloggy et al., 2025), and hydro-economic models may need to incorporate insurance dynamics to better capture how risk management influences pumping behavior. Our results call attention to the need to incorporate policy interactions in collective decision making.

The rest of this paper is organized as follows. Section 2 provides background on groundwater depletion and management policies, as well as more information on subsidies within the FCIP. In Section 3, we develop a conceptual model connecting GQRs to risk management costs. In Section 4, we discuss our dataset and the natural experiment used to explore the impact of GQRs on crop insurance prices and describe the empirical model we use to test that relationship. We present our results in Section 5. Finally, in Section 6, we conclude by discussing the implications of our work for policy design and future research.

2. Background

2.1 Groundwater depletion

Groundwater comprises the vast majority of the planet's liquid freshwater supply, with roughly 99% stored underground (Shiklomanov & Gleick, 1993). Groundwater has become the primary source of consumptive water for billions of people around the world (Jasechko & Perrone, 2021, Zektser & Everett, 2004). It is also an essential input into global food production (Siebert et. al 2010). Despite its importance, the global value of groundwater is difficult to price due to missing markets (Rouhi Rad et al., 2020), a growing population globally, the advancement of climate change, and uncertainty regarding groundwater depletion[1]. Groundwater depletion has

[1] *Groundwater depletion* has been defined as the multi-year withdrawal of groundwater from an aquifer at a rate faster than its replenishment, often causing groundwater level declines and volume reductions (Margat et al. 2006).

also been linked to issues with sea level rise (Konikow, 2011), deteriorating water quality (USGS, 2018), and lower levels of above-ground aquatic resources such as lakes and streams (Tuluram & Krishna, 2009, Brozović & Kuwayama, 2013).

Inefficient groundwater depletion results from individually optimal extraction that does not account for the external costs placed on other individuals extracting from the same stock (Shepler et al. 2019). This problem is further worsened by the fact that many local (and federal) governments around the world have failed to legislate groundwater in a timely manner prior to its scarcity approaching critical levels (Nayak 2009, Reddy 2005).[2] Evidence points toward local management of groundwater resources being preferred to national or global policy solutions (Foster et al. 2013), both for geographic and hydrogeologic reasons. A variety of policies have been implemented at the local-level around the world to curb groundwater depletion (Endo 2015), including direct regulation, market-based approaches, and community management (Ifft, Bigelow, & Savage, 2018, Drysdale & Hendricks, 2018, Kataoka, 2006).

2.2 Groundwater Management on the Ogallala Aquifer

Groundwater is also an essential resource in the US, making up 26% of the freshwater withdrawn (USGS, 2009). A key source of agricultural groundwater in the United States is the Ogallala Aquifer, which is the largest aquifer in the country and the source of 30% of all groundwater used for agricultural irrigation (Dennehy, 2000). The Ogallala Aquifer is situated in the High Plains region, providing water to residents of 215 counties in Texas, Oklahoma, Kansas, Nebraska, South Dakota, Wyoming, Colorado, and New Mexico (Gollehon & Winston, 2013). Previous estimates of the Ogallala Aquifer's value have exceeded $20 billion (Little, 2009), mostly due to its importance to the agricultural sector. The 112 million acres of land the aquifer is situated upon produces over a fifth of the US's corn, wheat, and cotton supply (Houston et al., 2013). Outside of agriculture, the Ogallala Aquifer also provides drinking water to over 2.3 million people (Houston et al., 2013).

The Ogallala Aquifer has traditionally been considered a common pool resource since producers fail to internalize costs imposed on other extractors (Lauer et al., 2018). This would suggest that the Ogallala is at high risk of depletion in the absence of any conservation policies. Previous depletion estimates of the Ogallala have determined that the aquifer, containing 3,608 km^3 of groundwater, loses 410 km^3 annually (USGS, 2018). The Ogallala's depletion from 2001 to 2008 was 32% of the total depletion from the previous 100 years. (Konikow, 2013). Depletion of the Ogallala Aquifer resulted in an annual loss of $110 million in value in Kansas alone between 1996 and 2005 (Fenichel et al., 2016).

[2] In some cases, policies can contribute directly to depletion. For example, in India, many agricultural groundwater users receive free electricity for pumping (Kondepati 2013).

Groundwater depletion on the Ogallala Aquifer is exacerbated by heterogenous management by the eight different states that overlay it. For example, in Kansas and Colorado, groundwater rights are managed through prior appropriation, where senior water rights holders are granted preference to junior holders (White & Krom, 1995), while Texas governs groundwater under "rule of capture", where landowners can withdraw as much groundwater as is feasible. Over the last few decades there has been a transition toward local management of groundwater resources. These local institutions have included "Groundwater Management Areas" in northern Texas, which mostly focus on monitoring use and identifying technology-based conservation solutions for their region (HPWD, 2022).

Nebraska has taken a different approach. The state has been split into "natural resource districts" (NRDs), which manage groundwater (among other resources) through a variety of quantity and quality regulations. These policies include tradable groundwater permits, restrictions on expanding the number of acres you can irrigate on your property, moratoriums on drilling any new wells, and GQRs. In some NRDs, these measures are automatically triggered when groundwater levels fall below a predetermined threshold. In others, the decision rests with NRD resource managers. In both cases, their enactment is difficult for farmers to anticipate, making these policies plausibly exogenous.

Of the policies mentioned, GQRs (called "pumping restrictions" in Kansas and "allocation schemes" in Nebraska) have received the most attention from researchers[3] (Drysdale & Hendricks, 2018, Ifft, Bigelow, & Savage, 2018, Deines et al. 2019). These policies typically restrict the amount of groundwater an agricultural producer can access within a set time period, ranging from one year to five, creating a binding constraint on their ability to access groundwater (Schoengold & Brozovic, 2018). In total, nine resource districts in Nebraska and one groundwater management area in Kansas have adopted a GQR as a means of conserving groundwater stocks.

One example of a GQR comes from the Sheridan 6 Local Enhanced Management Area (LEMA) in Kansas (Figure 1), which states that-

> *"Each irrigation water right within the Sheridan 6 LEMA shall be limited to a total maximum quantity of 55 inches per irrigated acre for the Sheridan 6 LEMA Period. This five-year quantity of 55 inches shall be known as the 'initial irrigation allocation', …"*

[3] Pumping restrictions were implemented at the local level in both Nebraska and Kansas.

In the Sheridan 6 LEMA, the GQR was initially instituted from January 2013 through December 2017, with a goal of diverting no more than 114,000 acre-feet of water during the five-year period (Sheridan 6 LEMA, 2012). On January 1, 2018, the GQR in the LEMA was renewed until December 31, 2022.

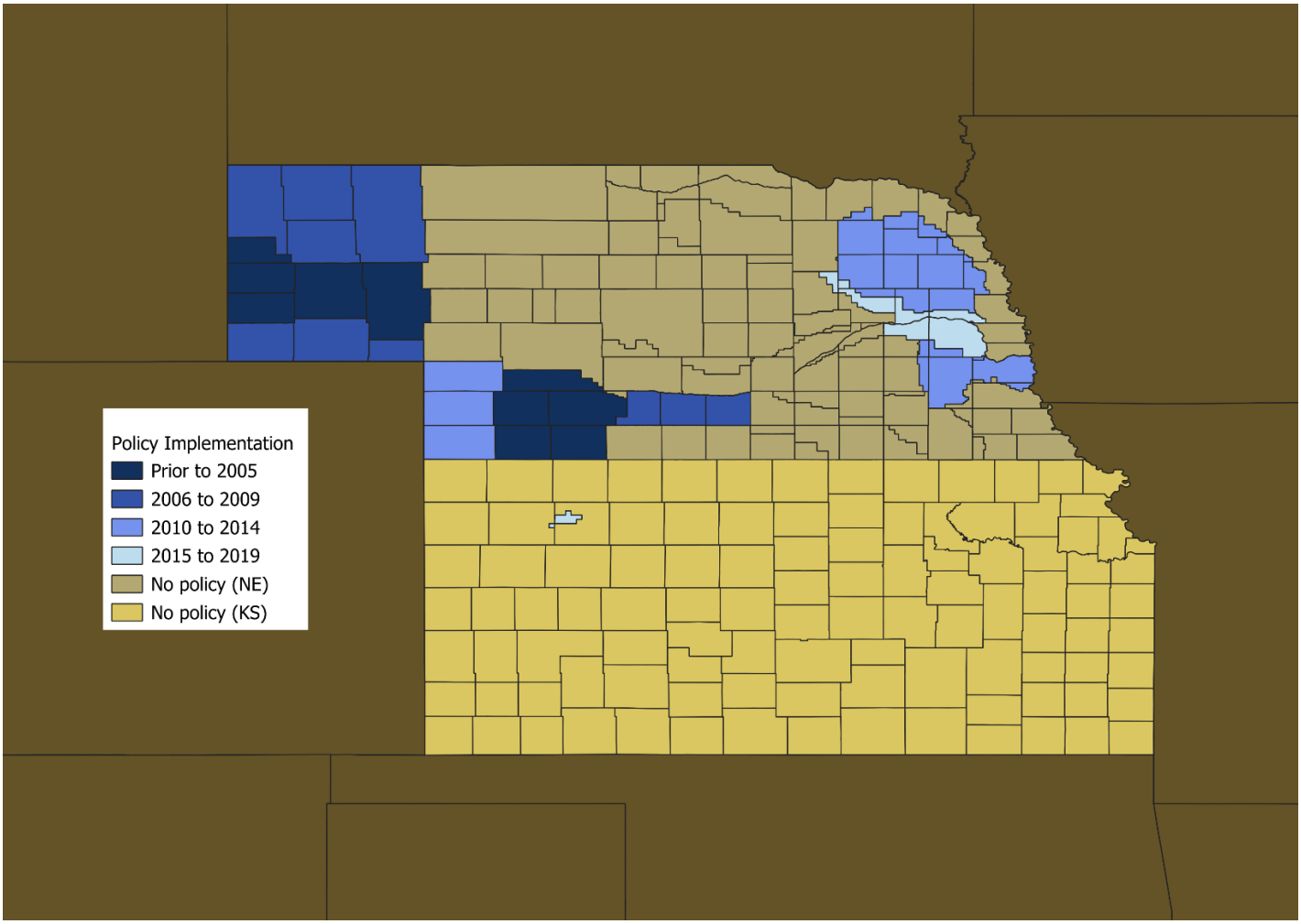


Figure 1: Map of pumping restriction coverage in Kansas in Nebraska from 2002 to 2016

Using a difference-in-differences econometric framework, Ifft, Bigelow, and Savage (2018) find that GQRs generally had no impact on farmland values in Nebraska from 1999 to 2012. However, they do find a heterogenous impact in parts of the state which rely more heavily upon irrigated crop production. Prior research focused on the GQR implemented in the Sheridan 6 LEMA found that the policy induced a 26% decline in irrigation across the district (Drysdale & Hendricks, 2018). That finding is supported by Deines et al. (2019), who find that the reduction

in irrigation mostly came through improvements in pumping efficiency and switching to crops that are less water intensive.

2.3 Insurance subsidies

The FCIP was created in 1938 to (i) provide income protection to farmers, (ii) stabilize farm buying power, and (iii) guarantee food supplies to consumers (NAIC, 2020). The program has been managed by the RMA of USDA since 1980. The FCIP functions as a public-private partnership where private insurance companies sell insurance products, and the federal government provides support by setting rates and providing financial support for operating expenses and re-insurance (Glauber, 2016). The FCIP provides several varieties of insurance products for producers, including yield insurance, revenue insurance, and others (Shields, 2009).

One of the key mechanisms through which the federal government supports the public-private partnership of the FCIP is by subsidizing a substantial portion of producers' insurance premiums, thereby reducing the cost of risk management and incentivizing crop insurance adoption. Roughly 60% of insurance policy premiums are paid by federal subsidies (Goodwin & Smith, 2013). The subsidy rates vary based on the crop insurance policy type and coverage level selected by the policyholder (Young, Vandeveer, & Schnepf, 2001). Subsidy rates typically decline as coverage levels increase, meaning producers receive less financial support per premium dollar for higher coverage levels (Yi, Bryant, & Richardson, 2020).

Evidence suggests that crop insurance subsidies have a distinct influence on a set of producer decisions. Higher subsidy levels have influenced farmers to plant riskier crops, insure more acreage, and increase the coverage level of their insurance policy (Yu & Sumner, 2018, Yu, Smith, & Sumer, 2018). Higher subsidies also incentive agricultural producers to use more water for irrigation (Ghosh, Miao, & Malikov, 2021). Ghosh, Miao, & Malikov (2021) find that increases in irrigation occur through surface water withdrawals, however, Sloggy et al. (2025) find that irrigation through groundwater applications can also increase with higher subsidy rates.

Groundwater access is a key determinant of agricultural production risk (Foster, Brozović, & Butler, 2017), implying that GQRs may substantially affect how farmers and federal insurance administrators perceive production risk. Such changes can impact the per-dollar cost of liability coverage, resulting in higher premiums for producers. Because crop insurance subsidies are calculated as a share of total premiums, higher premiums induced by GQRs could translate into greater public expenditures. This creates the potential for unintended policy interactions between federally funded crop insurance and locally implemented groundwater management policies.

3. Conceptual Framework

In this section, we outline the conceptual pathways through which GQRs may increase crop insurance expenditures and influence producer decisions. Figure 2 summarizes the main channels and corresponding hypotheses that guide our empirical analysis.

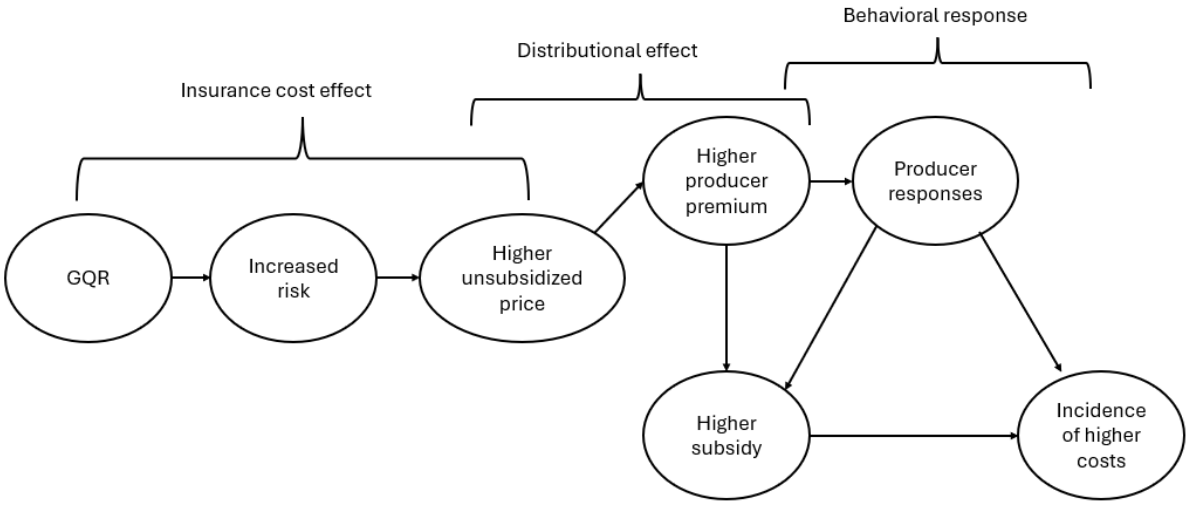


Figure 2: Hypothesized impact of GQRs on Crop Insurance Expenditures*. Implementation of a GQR in a groundwater management district increases the risk associated with irrigated production. This leads to a higher baseline (unsubsidized) insurance price through the "insurance cost effect." The higher unsubsidized price results in larger total insurance expenditures through increased producer premiums and government subsidies, constituting a "distributional effect." These changes, along with potential shifts in producer behavior, influence the incidence of higher insurance expenditures.*

Irrigation serves as a key risk management tool for farmers, particularly in drought-prone regions (Deb et. al, 2022). We hypothesize that when irrigation is restricted, farmers face more uncertainty in maintaining yields, prompting insurers to reassess the risk associated with providing coverage. This mechanism is what we refer to as the "insurance cost effect", where increased production risk leads to a higher baseline price of insurance. We begin by testing whether baseline (unsubsidized) crop insurance rates increase in regions that implement GQRs, reflecting higher production risk estimated by federal insurance administrators.

Higher baseline rates for a crop insurance policy imply that there will be a higher premium charged to farmers unless the increased expenditures are fully subsidized. Moreover, because crop insurance subsidies are typically structured as a percentage of the total premium, higher baseline rates also lead to larger subsidy payments by the federal government even without a change in the policy rate. We expect that both the premiums and subsidies per level of liability should increase for agricultural producers in the regions that implement GQRs.

Observed increases in insurance premiums caused by GQRs are likely to be shared between producers and the federal government. This "distributional effect" is illustrated in Figure 2, where higher unsubsidized insurance prices translate into both higher producer-paid premiums and increased government subsidies. We assess the incidence of GQRs by estimating how total subsidies and producer premiums respond at the county level.

However, rising insurance expenditures may also prompt producers to change how they manage risk, capturing the "behavioral response" pathway in Figure 2. Faced with higher premiums, producers may switch to insurance products with lower coverage levels or reduce the number of acres they insure, particularly on marginal land. These choices can decrease insurance expenditures but also reduce the expected benefit of insurance. To test for such responses, we examine how GQRs influence coverage level selection and insured acreage decisions.

Both the distributional and behavioral responses play a role in determining the incidence of increased risk management expenditures resulting from GQRs. We define incidence as the share of the total increase borne by producers (through premiums) versus the federal government (through subsidies). We estimate the incidence of these increased expenditures to understand how the financial burden of groundwater regulation falls across producers and the federal government.

4. Data and context

To estimate the impact of groundwater management policies on crop insurance rates, we construct a panel dataset of all counties with agricultural production above the Ogallala Aquifer from 2002 to 2016, a time period which saw multiple resource districts implement GQRs. Table 1 provides an overview of select variables in our analysis.

Our dataset reports the share of each county covered by groundwater management policies. The specific groundwater management policies include: a GQR, a stay on irrigated acres, or a moratorium on drilling new groundwater wells. Information regarding groundwater management policies, including implementation dates and policy specifics, were collected from a combination of information reported on natural resource district websites, email correspondence with district offices, and phone conversations with employees. Identifying variation in this research not only comes from the policies being passed at different points in time in our sample period, but also from the share of the county covered by a pumping restriction. Groundwater management policies in Nebraska are implemented at the resource district level, whose boundaries are not congruent to county lines, evidenced by the map in Figure 1, resulting in pumping restrictions covering varying shares of a county.

Table 1: Summary Statistics

Variable	Mean	Std. Dev.	Min.	Median	Max.	Obs.
Dependent Variables						
Unsubsidized Rate Parameter	0.05	0.03	0.01	0.04	0.28	2342
Total Policy Cost per Liability	0.14	0.06	0.03	0.13	0.47	2240
Premium per Liability	0.03	0.02	0.00	0.03	0.15	2240
Subsidy per Liability	0.05	0.02	0.01	0.05	0.22	2240
Coverage Level	0.69	0.09	0.00	0.70	1.00	2240
Insured Acres	26223.14	45186.08	0.00	0.00	238000	2342
Subsidized Premium (county-level, $1000s)	1390.96	1796.66	0.00	737.96	17115.53	2267
Subsidy (county-level, $1000s)	809.31	1041.64	0.00	435.30	10429.84	2267
Total Policy Cost (county-level, $1000s)	2200.28	2836.73	0.00	1180.24	27545.37	2267
Yield (bushels/acre)	88.59	91.46	0.00	0.00	232.50	2187
Independent Variables						
Share of county covered 'Groundwater Quantity Restriction'	0.01	0.11	0.00	0.00	1	2342
Share of county covered by 'Stay on Irrigated Acre'	0.07	0.24	0.00	0.00	1	2342
Share of county covered by 'Drilling Moratorium'	0.07	0.24	0.00	0.00	1	2342
Total Precipitation (mm)	552.64	172.06	119.82	539.26	1214.26	2342
Average Daily Max. Temperature (C)	19.99	2.56	11.85	20.06	26.76	2342
PDSI	0.65	2.78	-5.08	0.52	8.03	2342
Saturated Thickness (feet)	123.38	134.96	0.00	77.56	704.75	2342

We also use data on insurance related to irrigated corn in our study area. Insurance variables, including subsidy payments, policy premium amounts, liability values, insured acreage, and coverage levels,[4] were obtained from the USDA's SOB Reports (USDA, 2022). Insurance rate parameters, which are separated by crop and irrigation practice type, are obtained from RMA (RMA, 2021). We obtain data from NASS on the yield for each crop.

Our analysis includes controls for environmental and weather conditions—specifically, the Palmer Drought Severity Index (PDSI), temperature, and precipitation—as well as county-level measurements of saturated thickness in the Ogallala Aquifer. PDSI, obtained from NOAA (Dai et al. 2004, NCEI 2025) is measured specifically for agricultural land.[5] Daily average temperature and total precipitation over agricultural land by year were acquired from Gridmet (Abatzoglou, 2013). Saturated thickness, a measure of the distance between a water table and bedrock surface (USGS, 2012), is obtained from Haacker, Kendall, and Hyndman (2016).

[4] In the FCIP, “coverage level” refers to the percentage of expected revenue that is insured under a crop insurance policy and is chosen by the farmer. In the event of a crop loss, farmers should expect to receive an indemnity payment that is equal to the “coverage level” x “APH” x “price of crop”; where APH refers to a calculation of average yields in a farmer’s recent history. When realized revenue exceeds the insured revenue threshold (coverage level × APH × price), no indemnity is paid.

[5] Land deemed as "agricultural land" was determined by the USGS's National Land Cover Database

Empirical specification

After constructing our dataset, we estimate the effect of GQRs on crop insurance expenditures. Our fixed-effects model is specified as follows:

$$y_{ct} = \delta A_{ct} + \beta X_{ct} + \theta_c + \gamma_{st} + \varepsilon_{ct} \quad (1)$$

Where y_{ct} denotes our outcome of interest in county *c* and year *t*, aggregated across all crop insurance policy types. We estimate models for three classes of outcomes. First, we examine measures of crop insurance pricing, including the unsubsidized rate reported by the RMA and per-liability policy expenditures. Second, we consider insurance decisions made by irrigated corn producers, specifically their chosen coverage levels and the number of acres insured. Third, we estimate models where the outcome reflects the total expenditures of the crop insurance program, including federal subsidy payments, producer-paid premiums, and the sum of both.

A_{ct} represents the share of a county covered by a GQR in county *c* and year *t.* The goal of our research is to identify δ, the effect of GQRs on crop insurance expenditures and decisions. X_{ct} is a vector of controls that includes measures of groundwater depth (saturated thickness), the presence of other types of groundwater management policies (moratoriums on drilling wells or irrigating more acres), and weather (last year's total precipitation, average maximum temperature, and planting season PDSI). We include county-level fixed effects, denoted as θ_c, which account for any time-invariant heterogeneity in county *c*. We also include state-year fixed effects, γ_{st}, which account for any policies passed or statewide environmental shocks in state *s* in year *t*. ε_{ct} is the error term clustered at the county level.

5. Results

This section presents our main empirical findings on how groundwater quantity restrictions (GQRs) affect crop insurance pricing, agricultural producer insurance decisions, and risk management expenditures. We first assess the effect of GQRs on crop insurance pricing. Table 2 presents four specifications that depict how GQRs alter the cost structure of irrigated corn insurance. Column (1) shows the impact of GQRs on the unsubsidized insurance rate for irrigated corn. Coefficients describe the impact of implementing a GQR over 100% of a county's area. Our results indicate that GQRs increase the baseline price per dollar of liability before government support by $1.70 per $100 of liability, which represents a 35% increase in the unsubsidized insurance rate relative to the sample mean of 0.05.

Column (2) of Table 2 presents estimates of GQRs' impact on the total expenditures of crop insurance for irrigated corn, which includes both producer-paid premiums and federal subsidy contributions, per dollar of liability. We examine this outcome separately because it reflects the realized financial burden of insuring under a GQR regime, accounting for behavioral mechanisms like shifts in coverage level. Additionally, we disaggregate results by coverage level in Column (2), allowing us to evaluate whether the financial impacts of GQRs vary across different insurance choices.

The first row of Table 2, Column (2) reports the average effect of GQRs on total insurance expenditures (per liability) across all policies within a county-year. This estimate shows that GQRs are associated with a statistically significant increase in total insurance expenditures, raising total expenditures for irrigated corn of policies by $0.009 per dollar of liability. For context, the average amount of liability for irrigated corn in a county is $18.4 million, meaning that GQRs on average increase expenditures by $165 thousand at the county level. Results in the subsequent rows are disaggregated by coverage level, allowing us to assess whether the impact of GQRs on total program expenditures vary across different insurance choices. Each coefficient estimate is from estimating equation 1 using the dependent variable reported only for coverage levels in the range indicated on the left side of the table. We do not find that insurance expenditures differ significantly for policies at lower coverage levels. However, policies at the highest coverage levels (90-100%) observe an increase of $0.023 per dollar of liability in total crop insurance expenditures.

Column (3) of Table 2 contains estimates for the increase in insurance expenditures per dollar of liability that agricultural producers face. This is the policy premium after the application of federal insurance subsidy. Row 1 shows that there is not a statistically significant increase in producer's insurance expenditures per liability when looking across all coverage levels. We do find that there is a small increase ($0.003) in premiums per liability for producers who choose policies with coverage levels between 60 and 80%. The largest increase in premiums is observed in irrigated corn policies at the highest coverage levels (90-100%), with an increase of $0.008 per dollar of liability.

In Column (4) of Table 2, GQRs are associated with a $0.04 increase in federal subsidy payments per dollar of liability for irrigated corn, as shown in the aggregate estimate across all coverage levels (Row 1). Estimates using coverage-level subsamples (Rows 2–6) yield similar point estimates between $0.04 and $0.07. Consistent with other results in the table, we find that policies with the highest coverage level receive the largest increase in subsidies per dollar of liability.

Table 2: Dependent Variable - Policy Costs per Liability (levels)

Cov. lvl.	(1) Mean unsubsidized rate parameter	(2) Total policy cost per liability	(3) Subsidized Premium per liability	(4) Subsidy per liability
ALL	0.017***	0.009*	0.002	0.004**
	(0.004)	(0.005)	(0.002)	(0.002)
	2,342	*2,239*	*2,239*	*2,239*
50-59%	-	0.010**	0.002	0.004**
	-	(0.005)	(0.001)	(0.002)
	-	*1,964*	*1,964*	*1,964*
60-69%	-	0.010**	0.003*	0.004**
	-	(0.005)	(0.002)	(0.002)
	-	*2,032*	*2,032*	*2,032*
70-79%	-	0.010*	0.003*	0.003*
	-	(0.005)	(0.002)	(0.002)
	-	*2,003*	*2,003*	*2,003*
80-89%	-	0.010	0.003	0.004
	-	(0.007)	(0.003)	(0.002)
	-	*1,550*	*1,550*	*1,550*
90-100%	-	0.023***	0.008***	0.007***
	-	(0.006)	(0.002)	(0.002)
	-	*193*	*193*	*193*

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

All coefficients estimates presented are for the share of a county covered by a GQR.

Standard errors clustered at the county level in parentheses.

All estimates include controls for weather, groundwater depths, and other groundwater policies.

All estimates include State-Year and County fixed effects.

In Table 3, we evaluate how irrigated corn producers respond to increased crop insurance expenditures shown in Table 2. Columns (1) and (2) display coefficient estimates for the impact of GQRs on the average coverage level chosen (weighted by insured acreage) for irrigated corn insurance policies. We find that irrigated corn farmers choose policies with lower coverage levels in counties with greater coverage by GQRs. We find statistically significant effects in both linear and log specifications. The linear model implies a 1.5 percentage point reduction in coverage level, while the log model suggests a 1.8% decline, capturing the elasticity of response to an increasing share of a county covered by a GQR.

We also evaluate irrigated corn producers' decision about how many acres to insure in counties with greater coverage by GQRs in Table 3. Column (3) contains coefficient estimates for the impact on insured acres in levels, Column (4) has coefficient estimates on logged insured acres. In Row 1, we find no statistically significant change in insured acreage, whether measured in levels or logs. We do find a decline in the logged insured acres in the counties with greater coverage by GQRs in some individual coverage level ranges. For example, we find a statistically

significant coefficient estimate of -0.159 for the impact of GQRs on insured acreage with irrigated corn policies with coverage levels between 60 and 69%. That means that if a county went from no coverage by a GQR to being completely covered by the policy, there would be a 15.9% decline in the number of acres insured with coverage levels between 60 and 69%.

Table 3: Dependent Variable - Insured acres & coverage

Cov. lvl.	(1) Coverage Level	(2) Ln(Cov. Level)	(3) Insured acres	(4) Ln(Insured acres)
ALL	-0.015***	-0.018**	1937.925	-0.050
	(0.006)	(0.008)	(1600.762)	(0.044)
	2,126	*2,235*	*2,266*	*2,239*
50-59%	-	-	-1326.170	-0.517***
	-	-	(3429.551)	(0.165)
	-	-	*1,965*	*1,964*
60-69%	-	-	-3400.072	-0.159***
	-	-	(4555.480)	(0.031)
	-	-	*2,033*	*2,032*
70-79%	-	-	694.829	-0.028
	-	-	(2875.099)	(0.063)
	-	-	*2,004*	*2,003*
80-89%	-	-	-2773.185	-0.153*
	-	-	(4423.959)	(0.086)
	-	-	*1,550*	*1,550*
90-100%	-	-	-1154.948	-0.306
	-	-	(6573.747)	(0.310)
	-	-	*193*	*193*

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

All coefficients estimates presented are for the share of a county covered by a GQR.

Standard errors clustered at the county level in parentheses.

All estimates include controls for weather, groundwater depths, and other groundwater policies.

All estimates include State-Year and County fixed effects.

Finally, Table 4 investigates how the changes in insurance pricing and coverage choices driven by GQRs translate into total program expenditures. In Column (1), we measure the change in overall crop insurance expenditures at the county level, measured as total premium payments plus total subsidies. The first row shows results pooled across all coverage levels, while subsequent rows break the analysis out by coverage range by estimating equation 1 on dependent variables only from the coverage ranges indicated on the left-hand side of the table. In Row 1, we find an increase in total crop insurance expenditures. Our coefficient estimate

indicates that counties moving from no GQR coverage to full coverage experience a $1.06 million increase in total insurance expenditures. We find statistically significant increases in total risk management expenditures across all coverage ranges, except for policies with coverage levels between 80% and 89%. These results suggest that GQRs lead to broad-based increases in insurance program expenditures, regardless of producers' specific coverage choices.

Table 4: Dependent Variable - Policy costs (levels)

Cov. lvl.	(1) Total policy cost ($1000s)	(2) Subsidy ($1000s)	(3) Subsidized Premium ($1000s)
ALL	1063.320**	683.430**	379.890**
	(444.666)	(291.010)	(154.074)
	2,266	*2,266*	*2,266*
50-59%	660.460*	433.299*	227.161**
	(343.916)	(229.389)	(114.901)
	1,965	*1,965*	*1,965*
60-69%	587.403*	385.468*	201.936*
	(331.184)	(219.397)	(112.188)
	2,033	*2,033*	*2,033*
70-79%	949.765**	615.081**	334.684**
	(390.319)	(258.805)	(131.751)
	2,004	*2,004*	*2,004*
80-89%	457.176	296.944	160.232
	(317.829)	(210.487)	(107.656)
	1,550	*1,550*	*1,550*
90-100%	1068.497*	698.391*	370.106*
	(587.458)	(404.638)	(184.954)
	193	*193*	*193*

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

All coefficients estimates presented are for the share of a county covered by a GQR.

Standard errors clustered at the county level in parentheses; number of observations are italicized.

All estimates include controls for weather, groundwater depths, and other groundwater policies.

All estimates include State-Year and County fixed effects.

With evidence that GQRs increase the total expenditures of crop insurance, we next assess how this added financial burden is shared between agricultural producers and the federal government. In Columns (2) and (3) of Table 4, we separately estimate the effects of GQRs on the amount of subsidy paid by the government to the crop insurance program, and payments made by farmers which is the premium paid after subsidies are applied. The results show that both producers and the federal government face higher expenditures when GQRs are

implemented. For counties under full coverage, subsidies increase by $690 thousand and producer premiums by $380 thousand This implies that the government shoulders approximately 64% of the additional burden, a pattern that generally persists across coverage levels.[6]

In the Appendix, we report results from alternative specifications of our econometric model. In Tables A1 – A3, we evaluate the robustness of our main coefficient estimates by re-estimating the models (i) without any controls and (ii) excluding saturated thickness as a control to address potential endogeneity between GQRs and crop insurance prices that related to the timing of changes in saturated thickness. The estimated coefficients remain stable across these specifications. In Table A4, we examine whether GQRs affect crop yields or insured losses. We find some evidence that irrigated corn yields are higher in counties with greater GQR coverage, which may reflect farmers concentrating water for irrigated corn on higher quality acres. There is no corresponding effect on insured losses (indemnity payments).

As a placebo test, we analyze whether GQRs influence insurance rates for non-irrigated (dryland) corn in Table A5. We find no such effect, suggesting the relationship is specific to irrigated production and not due to broader regional factors affecting all corn insurance rates. Finally, in Figures A1 to A4, we use the method described in Callaway & Sant'Anna (2021) and estimate our model using a discretized treatment variable where we define a county as treated if 10% of the county is covered by a GQR. The figures show treatment effects averaged by event time and broadly confirm our main results from Table 2 that show that GQRs increase the price of crop insurance and related per-liability costs such as total expenditures, subsidy, and premium.

6. Discussion and Conclusion

Groundwater is a critical input in agriculture, and policies that limit its use can have broad implications for producers. While prior research has examined the ways crop insurance influences groundwater use (Sloggy et al., 2025, Deryugina & Konar, 2017), we present new evidence that groundwater regulations also affect crop insurance expenditures. We show that GQRs raise crop insurance prices, and that the resulting increase in expenditures is shared by agricultural producers and the federal government. In response to higher premiums, farmers shift toward lower coverage levels, reducing the financial protection they receive from insurance on the intensive margin (Table 3). This finding suggests that local policies unrelated to

[6] One notable exception is the 80–89% range, where the impact is not statistically significant, similar to Column 1 of Table 4.

insurance can influence how farmers manage risk, and points to a need for economists to consider these interactions across a range of agricultural and resource systems.

In this study, we find that limiting access to groundwater increases crop insurance expenditures. Specifically, our estimates in Table 2 show that GQRs raise the baseline (unsubsidized) price of crop insurance by 35 percent for irrigated corn producers. This finding highlights how conservation policies can affect farmers not only through water access but also through changes in risk management. Accounting for these indirect effects is crucial to developing more robust groundwater policy. Better coordination is needed by policymakers for both environmental regulations and federal risk management programs to mitigate these indirect effects of conservation policy. The increased risk could be mitigated through policy design that incorporates greater flexibility or improved compliance options for agricultural producers (Schoengold & Brozovic, 2018, Steiner et al., 2021). Conservation policies that are similar to GQRs should be evaluated not only on their expected outcomes but also on the additional uncertainty they impose. Our findings suggest that the federal government could consider how crop insurance pricing reflects local policy conditions.

A discovery from this study is that, through increased subsidy payments, the federal government bears most of the increased expenditures on crop insurance caused by GQRs. In counties fully subject to GQRs, federal subsidy payments increase by 84% above the average (see Tables 1 & 4), covering approximately 64% of the total rise in crop insurance expenditures. Subsidies function as a financial cushion for producers facing heightened risk under resource conservation policies, but they also represent a public cost (Goodwin & Smith, 2013, Glauber, 2016). Making these expenditures more transparent and responsive could help manage future fiscal exposure, and there may be value in re-evaluating subsidy rates to reflect regional conservation efforts (Woodard & Verteramo-Chiu, 2017, Classen et al., 2004).

Our analysis reveals that GQRs can influence groundwater use not only directly, but also indirectly through increased risk management expenditures. This finding adds a new dimension to the existing literature by revealing a new channel through which GQRs impact water use. Drysdale & Hendricks (2018) estimate that GQRs reduce groundwater withdrawals by 26%. Our findings show that GQRs also raise crop insurance prices, increasing the financial risk borne by farmers. Higher insurance prices are known to reduce groundwater withdrawals (Sloggy et al., 2025), indicating that GQRs may lower water use through this risk management cost channel. Effective conservation policy design requires accounting for this indirect effect and policy interactions that influence overall outcomes.

These findings offer valuable insight into the relationship between resource conservation policies and crop insurance, but they should be interpreted with caution. The study relies on observational data and does not capture all dimensions of policy implementation and

agricultural production. We are unable to estimate how stringent a groundwater restriction was on farmers' ability to withdraw in a given year, meaning we merely estimate the effect of a GQR's presence in a county, not its intensity at limiting water use. Though we control for price using state-year FEs, we do not fully account for potential price effects, such as changes in crop value or input costs, which may alter both the actuarial basis of insurance premiums and producers' willingness to purchase coverage. Unlike other studies on groundwater conservation policies (Drysdale & Hendricks, 2018, Ifft, Bigelow, & Savage, 2018) that observe the impact of policies at the well level, we observe impacts at the county level. Analyzing impacts at the county level constrains our ability to capture producer-level variation in policy stringency and directly connect GQRs to individual insurance decisions.

Another limitation of this study is its geographic focus on the Ogallala Aquifer region, which may limit the generalizability of our findings to other agricultural settings. The economic and hydrologic characteristics of this region, such as crop composition, climate conditions, and institutional structures, may differ significantly from those in other areas where groundwater policies are implemented. As a result, caution should be exercised when extrapolating these results to areas like California, where the elasticity of irrigation demand may differ substantially (Hrozincek et al., 2022, Burlig, Preonas, & Woerman, 2021).[7] Comparative evidence from studies in other regions could help benchmark how groundwater policy impacts vary across contexts.

Additionally, our analysis focuses exclusively on irrigated corn and a single crop insurance product type. While this decision reflects the economic significance of corn in the Ogallala region and the structure of available data, it limits our ability to assess whether similar effects would be observed for other crops or insurance policy types. Future research should explore whether the patterns we find exist in a broader range of commodities and production environments.

Future research on the relationship between local resource management and risk management should aim to clarify how conservation policy impacts differ based on enforcement stringency and resource type. While this study focuses on groundwater, similar interactions may exist for policies conserving the stock of common-pool resources such as surface water, forests, or fisheries. Examining these systems could reveal whether the shifts in risk exposure and public cost-sharing observed in our study are consistent across ecological and institutional settings. Future research should also take advantage of variation in policy design and enforcement across

[7] For example, Hrozincek et. al 2022 use data from eastern CO to find that the elasticity of groundwater demand relative to the price of electricity is -0.49. Meanwhile, Burlig, Preonas, & Woerman; 2021 use data from California to find that same elasticity to be -0.76.

resource districts to identify how the intensity of regulation influences behavioral responses and the cost of risk management.

Finally, future work would benefit from data that supports more fine-scale, within-county analysis of exposure and outcomes. Field-level data on irrigation and insurance decisions would allow researchers to observe more granular exposure to policy, account for intra-county heterogeneity, and implement alternative identification strategies. Together, these extensions could help generalize our findings and inform more effective integration of conservation and risk management policy.

Appendix

Table A1: Dependent Variable - Policy Costs per Liability (levels)

Cov. lvl.	(1) Mean unsubsidized rate parameter	(2) Mean unsubsidized rate parameter	(3) Total policy cost per liability	(4) Total policy cost per liability	(5) Subsidized Premium per liability	(6) Subsidized Premium per liability	(7) Subsidy per liability	(8) Subsidy per liability
ALL	0.017***	0.017***	0.009*	0.010**	0.002	0.002	0.004**	0.004**
	(0.004)	(0.005)	(0.005)	(0.005)	(0.002)	(0.002)	(0.002)	(0.002)
	2,342	*2,342*	*2,239*	*2,239*	*2,239*	*2,239*	*2,239*	*2,239*
50-59%	-	-	0.010**	0.011**	0.002	0.002	0.004**	0.005**
	-	-	(0.005)	(0.005)	(0.001)	(0.001)	(0.002)	(0.002)
	-	-	*1,964*	*1,964*	*1,964*	*1,964*	*1,964*	*1,964*
60-69%	-	-	0.010**	0.011**	0.003*	0.003	0.004**	0.004**
	-	-	(0.005)	(0.005)	(0.002)	(0.002)	(0.002)	(0.002)
	-	-	*2,032*	*2,032*	*2,032*	*2,032*	*2,032*	*2,032*
70-79%	-	-	0.010**	0.011**	0.003*	0.003	0.004**	0.004**
	-	-	(0.005)	(0.005)	(0.002)	(0.002)	(0.002)	(0.002)
	-	-	*2,003*	*2,003*	*2,003*	*2,003*	*2,003*	*2,003*
80-89%	-	-	0.010	0.011	0.003	0.003	0.004*	0.004*
	-	-	(0.007)	(0.007)	(0.003)	(0.003)	(0.002)	(0.002)
	-	-	*1,550*	*1,550*	*1,550*	*1,550*	*1,550*	*1,550*
90-100%	-	-	0.020***	0.021***	0.007***	0.007***	0.007***	0.007***
	-	-	(0.005)	(0.004)	(0.002)	(0.002)	(0.002)	(0.001)
	-	-	*193*	*193*	*193*	*193*	*193*	*193*
Policy Controls	Yes	No	Yes	No	Yes	No	Yes	No
Groundwater Controls	No	No	No	No	No	No	No	No
Weather Controls	Yes	No	Yes	No	Yes	No	Yes	No
County Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

All coefficients estimates presented are for the share of a county covered by a GQR.

Standard errors clustered at the county level in parentheses.

All estimates include controls for weather, groundwater depths, and other groundwater policies.

All estimates include State-Year and County fixed effects.

Table A2: Dependent Variable - Insured acres & coverage

Cov. lvl.	(1) Coverage Level	(2) Coverage Level	(3) Ln(Cov. Level)	(4) Ln(Cov. Level)	(5) Insured acres	(6) Insured acres	(7) Ln(Insured acres)	(8) Ln(Insured acres)
ALL	-0.016***	-0.015**	-0.018**	-0.019**	1886.363	2174.790	-0.048	-0.046
	(0.006)	(0.006)	(0.008)	(0.008)	(1633.958)	(1683.950)	(0.042)	(0.042)
	2,239	*2,239*	*2,235*	*2,235*	*2,266*	*2,266*	*2,239*	*2,239*
50-59%	-	-	-	-	-1594.752	-911.566	-0.514***	-0.445**
	-	-	-	-	(3629.063)	(3713.245)	(0.166)	(0.175)
	-	-	-	-	*1,965*	*1,965*	*1,964*	*1,964*
60-69%	-	-	-	-	-3678.308	-3098.994	-0.158***	-0.133***
	-	-	-	-	(4735.797)	(4872.337)	(0.031)	(0.035)
	-	-	-	-	*2,033*	*2,033*	*2,032*	*2,032*
70-79%	-	-	-	-	493.542	752.711	-0.026	-0.043
	-	-	-	-	(3055.867)	(2932.965)	(0.061)	(0.057)
	-	-	-	-	*2,004*	*2,004*	*2,003*	*2,003*
80-89%	-	-	-	-	-2924.334	-2681.528	-0.152*	-0.166*
	-	-	-	-	(4566.251)	(4451.095)	(0.088)	(0.097)
	-	-	-	-	*1,550*	*1,550*	*1,550*	*1,550*
90-100%	-	-	-	-	-681.725	-7102.984	-0.404	-0.263
	-	-	-	-	(5452.858)	(5225.750)	(0.270)	(0.168)
	-	-	-	-	*193*	*193*	*193*	*193*
Policy Controls	Yes	No	Yes	No	Yes	No	Yes	No
Groundwater Controls	No	No	No	No	No	No	No	No
Weather Controls	Yes	No	Yes	No	Yes	No	Yes	No
County Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

All coefficients estimates presented are for the share of a county covered by a GQR.

Standard errors clustered at the county level in parentheses.

All estimates include controls for weather, groundwater depths, and other groundwater policies.

All estimates include State-Year and County fixed effects.

Table A3: Dependent Variable - Policy costs (levels)

Cov. lvl.	(1) Total policy cost ($1000s)	(2) Total policy cost ($1000s)	(3) Subsidy ($1000s)	(4) Subsidy ($1000s)	(5) Subsidized Premium ($1000s)	(6) Subsidized Premium ($1000s)
ALL	1059.249**	1049.882**	680.854**	674.434**	378.396**	375.449**
	(445.538)	(439.623)	(291.655)	(287.725)	(154.293)	(152.383)
	2,266	*2,266*	*2,266*	*2,266*	*2,266*	*2,266*
50-59%	635.467*	699.935*	417.163*	457.128*	218.304*	242.806*
	(343.931)	(368.032)	(229.386)	(244.934)	(114.923)	(123.478)
	1,965	*1,965*	*1,965*	*1,965*	*1,965*	*1,965*
60-69%	567.139*	631.695*	372.507*	412.434*	194.632*	219.261*
	(333.384)	(357.177)	(220.851)	(236.258)	(112.926)	(121.325)
	2,033	*2,033*	*2,033*	*2,033*	*2,033*	*2,033*
70-79%	938.471**	953.654**	607.824**	616.112**	330.647**	337.542**
	(392.646)	(389.727)	(260.360)	(258.722)	(132.516)	(131.284)
	2,004	*2,004*	*2,004*	*2,004*	*2,004*	*2,004*
80-89%	445.934	486.613	289.709	314.589	156.225	172.024
	(316.268)	(333.173)	(209.451)	(220.575)	(107.136)	(112.897)
	1,550	*1,550*	*1,550*	*1,550*	*1,550*	*1,550*
90-100%	1076.128*	827.684	697.306*	541.133	378.822**	286.551
	(572.869)	(671.631)	(395.779)	(460.521)	(179.469)	(213.074)
	193	*193*	*193*	*193*	*193*	*193*
Policy Controls	Yes	No	Yes	No	Yes	No
Groundwater Controls	No	No	No	No	No	No
Weather Controls	Yes	No	Yes	No	Yes	No
County Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
State-Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

All coefficients estimates presented are for the share of a county covered by a GQR.

Standard errors clustered at the county level in parentheses; number of observations are italicized.

All estimates include controls for weather, groundwater depths, and other groundwater policies.

All estimates include State-Year and County fixed effects.

Table A4: Dependent Variable: Yield & indemnity payments (irrigated corn)

Cov. lvl	(1) Irrigated corn yield	(2) Total indemnity ($1000s)	(3) Indemnity per insured acre ($1000s)
ALL	21.102*	646.7	-0.0016
	(12.471)	(541.1)	(0.005)
Observations	2,187	2,266	1,079

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

All coefficients estimates presented are for the share of a county covered by a GQR.

Standard errors clustered at the county level in parentheses.

Includes Year fixed effects.

Table A5: Dependent Variable - Policy Costs per Liability (non-irrigated corn)

Cov. lvl.	(1) Mean unsubsidized rate parameter	(2) Total policy cost per liability	(3) Subsidized Premium per liability	(4) Subsidy per liability
ALL	0.005	0.001	0.003	-0.001
	(0.007)	(0.013)	(0.004)	(0.005)
	1,740	*1,707*	*1,707*	*1,707*
50-59%	-	-0.003	-0.001	-0.001
	-	(0.018)	(0.005)	(0.007)
	-	*1,491*	*1,491*	*1,491*
60-69%	-	-0.002	0.003	-0.002
	-	(0.013)	(0.004)	(0.005)
	-	*1,569*	*1,569*	*1,569*
70-79%	-	0.001	0.003	-0.001
	-	(0.012)	(0.003)	(0.004)
	-	*1,569*	*1,569*	*1,569*
80-89%	-	-0.002	0.003	-0.003
	-	(0.010)	(0.004)	(0.004)
	-	*1,347*	*1,347*	*1,347*
90-100%	-	0.009	0.005	0.002
	-	(0.017)	(0.006)	(0.006)
	-	*121*	*121*	*121*

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

All coefficients estimates presented are for the share of a county covered by a GQR.

Standard errors clustered at the county level in parentheses.

All estimates include controls for weather, groundwater depths, and other groundwater policies.

All estimates include State-Year and County fixed effects.

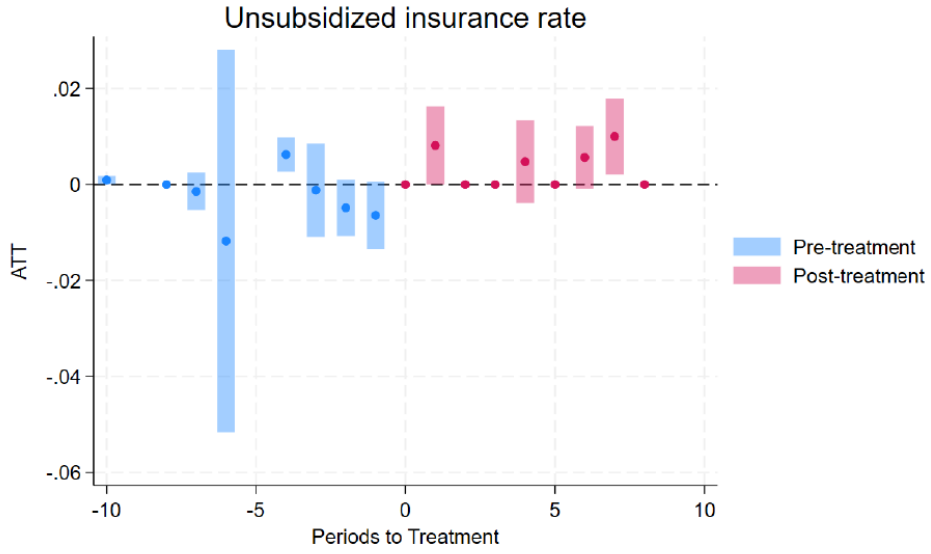


Figure A1: Santana-Callaway Difference-in-Difference estimates with unsubsidized rate parameter as dependent variable. Treatment variable is a binary indicator if a county has more than 10% of its land covered by a pumping restriction (never-treated as control group).

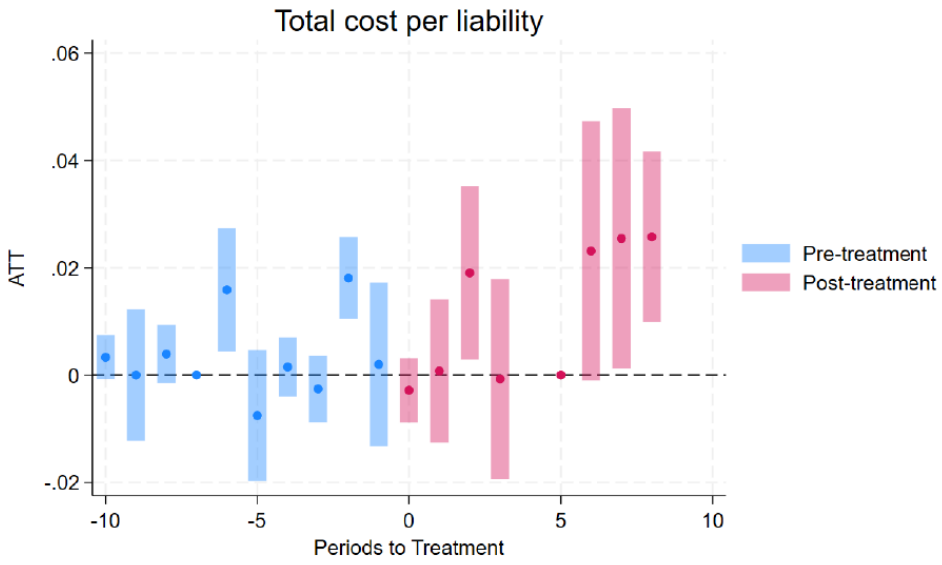


Figure A2: Santana-Callaway Difference-in-Difference estimates with total cost per unit of liability as dependent variable. Treatment variable is a binary indicator if a county has more than 10% of its land covered by a pumping restriction (never-treated as control group).

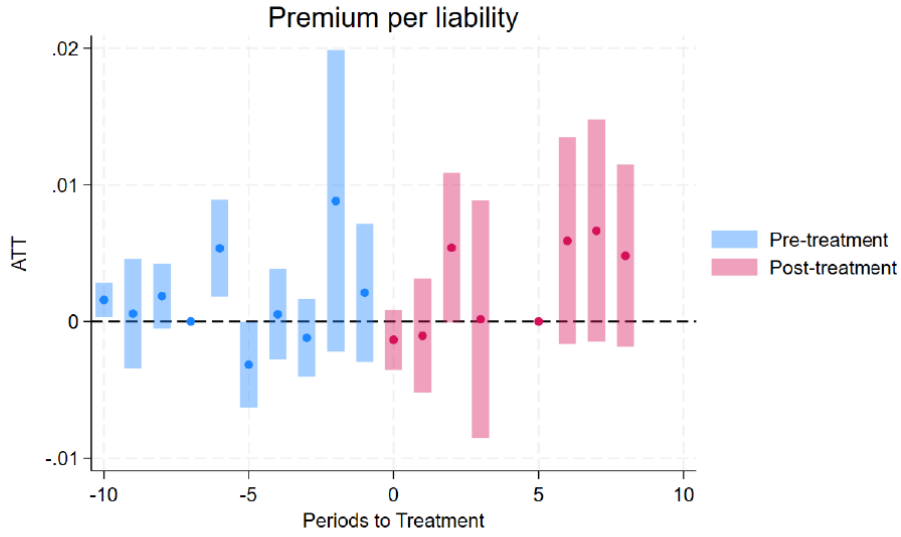


Figure A3: Santana-Callaway Difference-in-Difference estimates with premium per unit of liability as dependent variable. Treatment variable is a binary indicator if a county has more than 10% of its land covered by a pumping restriction (never-treated as control group).

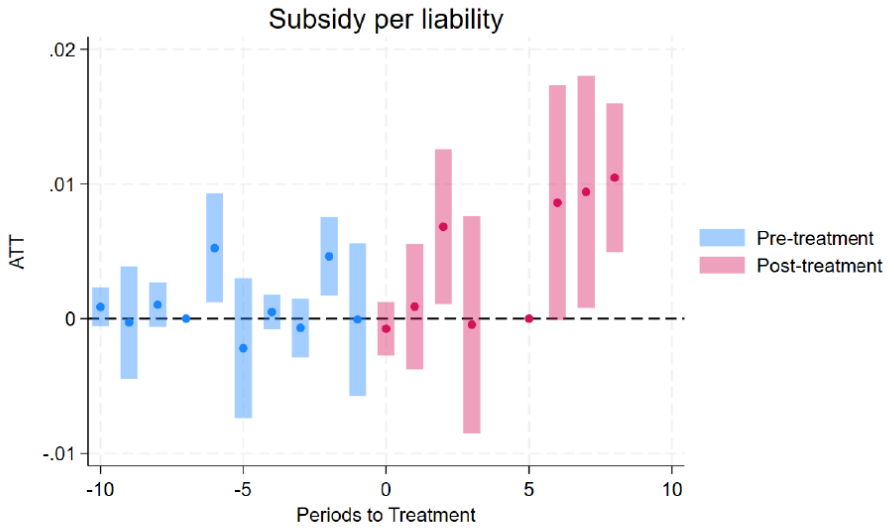


Figure A4: Santana-Callaway Difference-in-Difference estimates with subsidy per unit of liability as dependent variable. Treatment variable is a binary indicator if a county has more than 10% of its land covered by a pumping restriction (never-treated as control group).

Citations

1. Aeschbach-Hertig, Werner, and Tom Gleeson. "Regional strategies for the accelerating global problem of groundwater depletion." *Nature Geoscience* 5.12 (2012): 853-861.

2. Kuwayama, Y., & Brozović, N. (2013). The regulation of a spatially heterogeneous externality: Tradable groundwater permits to protect streams. *Journal of Environmental Economics and Management*, *66*(2), 364-382.

3. Bennear, L. S., & Stavins, R. N. (2007). Second-best theory and the use of multiple policy instruments. *Environmental and Resource economics*, *37*, 111-129.

4. Burlig, F., Preonas, L., & Woerman, M. (2021). Energy, groundwater, and crop choice. *NBER Working Paper*, (w28706).

5. Burnett, K., & Wada, C. A. (2014). Optimal groundwater management when recharge is declining: a method for valuing the recharge benefits of watershed conservation. *Environmental Economics and Policy Studies*, *16*, 263-278.

6. Callaway, B., & Sant'Anna, P. H. (2021). Difference-in-differences with multiple time periods. *Journal of econometrics*, *225*(2), 200-230.

7. Carlson, A. E. (2003). Federalism, preemption, and greenhouse gas emissions. *UC Davis L. Rev.*, *37*, 281.

8. Claassen, R., Breneman, V. E., Bucholtz, S., Cattaneo, A., Johansson, R. C., & Morehart, M. J. (2004). Environmental compliance in US agricultural policy: past performance and future potential.

9. Coble, K. H., & Barnett, B. J. (2013). Why do we subsidize crop insurance?. *American Journal of Agricultural Economics*, *95*(2), 498-504.

10. de Frutos Cachorro, Julia, Jesús Marín-Solano, and Jorge Navas. "Competition between different groundwater uses under water scarcity." *Water Resources and Economics* 33 (2021): 100173.

11. Deb, P., Moradkhani, H., Han, X., Abbaszadeh, P., & Xu, L. (2022). Assessing irrigation mitigating drought impacts on crop yields with an integrated modeling framework. *Journal of Hydrology*, *609*, 127760.

12. Deines, J. M., Kendall, A. D., Butler, J. J., & Hyndman, D. W. (2019). Quantifying irrigation adaptation strategies in response to stakeholder-driven groundwater management in the US High Plains Aquifer. Environmental Research Letters, 14(4), 044014.

13. Dennehy, K. F. (2000). High Plains regional ground-water study. US Department of the Interior, US Geological Survey.

14. Deryugina, T., & Konar, M. (2017). Impacts of crop insurance on water withdrawals for irrigation. *Advances in Water Resources*, *110*, 437-444.

15. Drysdale, Krystal M., and Nathan P. Hendricks. "Adaptation to an irrigation water restriction imposed through local governance." *Journal of Environmental Economics and Management* 91 (2018): 150-165.

16. Edwards, E. C. (2016). What lies beneath? Aquifer heterogeneity and the economics of groundwater management. *Journal of the Association of Environmental and Resource Economists*, *3*(2), 453-491.

17. Endo, T. (2015). Groundwater management: a search for better policy combinations. *Water Policy*, 17(2), 332.

18. Foster, T., Brozović, N., & Butler, A. P. (2017). Effects of initial aquifer conditions on economic benefits from groundwater conservation. *Water Resources Research*, *53*(1), 744-762.

19. Foster, S., Chilton, J., Nijsten, G. J., & Richts, A. (2013). Groundwater—a global focus on the 'local resource'. *Current opinion in environmental sustainability*, 5(6), 685-695.

20. Frankel, Z., Halberg, N., Nemati, M., Dinar, A., & Crespo, D. (2024). Climate Crisis is Straining the Colorado River's Complex Policy Architecture. Choices, 36(4), 1-7.

21. Ghosh, P. N., Miao, R., & Malikov, E. (2021). Crop insurance premium subsidy and irrigation water withdrawals in the western United States. *The Geneva Papers on Risk and Insurance-Issues and Practice*, 1-25.

22. Gisser, M., & Sanchez, D. A. (1980). Competition versus optimal control in groundwater pumping. *Water resources research*, *16*(4), 638-642.

23. Glauber, J. W. (2016). Crop insurance and private sector delivery: Reassessing the public-private partnership.

24. Gollehon, N. & Winston, B. (2013). Groundwater Irrigation and Water Withdrawals: The Ogallala Aquifer Initiative. REAP Reports. NRCS-USDA. Economic Series Number 1, August 2013.

25. Goodwin, B. K., Vandeveer, M., & Deal, J. (2001). The Federal Crop Insurance Program-An Empirical Analysis Of Regional Differences In Acreage Response And Participation.

26. Goodwin, B. K., & Smith, V. H. (2013). What harm is done by subsidizing crop insurance?. *American Journal of Agricultural Economics*, *95*(2), 489-497.

27. Goulder, L. H., & Stavins, R. N. (2011). Challenges from state-federal interactions in US climate change policy. *American Economic Review*, *101*(3), 253-257.

28. Guilfoos, T., Pape, A. D., Khanna, N., & Salvage, K. (2013). Groundwater management: The effect of water flows on welfare gains. *Ecological Economics*, *95*, 31-40.

29. Guru, M., & Horne, J. (2024). *The Ogallala Aquifer* (Vol. 48). WIT Press.

30. Haacker, E.M., Kendall, A.D. and Hyndman, D.W., 2016. Water level declines in the High Plains Aquifer: Predevelopment to resource senescence. Groundwater, 54(2), pp.231-242.

31. Houston, Natalie A., et al. 2013. Geodatabase Compilation of Hydrogeologic, Remote Sensing, and Water-Budget-Component Data for the High Plains Aquifer, 201. U.S. Geological Service Report. 2013.

32. Hrozencik, R. A., Manning, D. T., Suter, J. F., Goemans, C., & Bailey, R. T. (2017). The heterogeneous impacts of groundwater management policies in the Republican River Basin of Colorado. *Water Resources Research*, *53*(12), 10757-10778.

33. Hrozencik, R. A., Manning, D. T., Suter, J. F., & Goemans, C. (2022). Impacts of Block-Rate Energy Pricing on Groundwater Demand in Irrigated Agriculture. *American Journal of Agricultural Economics*, *104*(1), 404-427.

34. High Plains Water District (2022). Agricultural Conservation. Accesses on May 14, 2022 at hpwd.org

35. Ifft, Jennifer, Daniel P. Bigelow, and Jeffrey Savage. "The impact of irrigation restrictions on cropland values in Nebraska." *Journal of agricultural and resource economics* (2018): 195-214.

36. Jasechko, S., & Perrone, D. (2021). Global groundwater wells at risk of running dry. Science, 372(6540), 418-421.

37. Kataoka, Y. (2006). Towards sustainable groundwater management in Asian cities-lessons from Osaka. *International Review for Environmental Strategies*, 6(2), 269-290.

38. Konikow, L. F. (2011). Contribution of global groundwater depletion since 1900 to sea-level rise. Geophysical Research Letters, 38(17).

39. Konikow, L. F. (2013). Groundwater depletion in the United States (1900-2008). Reston, Virginia: US Department of the Interior, US Geological Survey.

40. Koundouri, Phoebe. "Current issues in the economics of groundwater resource management." Journal of Economic Surveys 18.5 (2004): 703-740.

41. Lauer, S., Sanderson, M. R., Manning, D. T., Suter, J. F., Hrozencik, R. A., Guerrero, B., & Golden, B. (2018). Values and groundwater management in the Ogallala Aquifer region. Journal of Soil and Water Conservation, 73(5), 593-600.

42. Leach, W. D., An, B. Y., & Tang, S. Y. (2021). Evaluating California's sustainable groundwater management act: the first five years of governance and planning. JAWRA Journal of the American Water Resources Association, 57(6), 972-989.

43. Lejars, C., Fusillier, J. L., Bouarfa, S., Coutant, C., Brunel, L., & Rucheton, G. (2012). Limitation of agricultural groundwater uses in Beauce (France): What are the impacts on farms and on the food-processing sector?. *Irrigation and Drainage*, *61*, 54-64.

44. Little, J. B. (2009). The Ogallala aquifer: Saving a vital US water source. Scientific American, 1.

45. Merrill, N. H., & Guilfoos, T. (2018). Optimal groundwater extraction under uncertainty and a spatial stock externality. *American journal of agricultural economics*, *100*(1), 220-238.

46. National Centers for Environmental Information. (2025) *Climate at a Glance: U.S. Time Series – Palmer Drought Severity Index*. National Oceanic and Atmospheric Administration. Accessed August 6, 2025. https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/national/time-series/110/pdsi

47. Nayak, S. (2009). Distributional inequality and groundwater depletion: An analysis across major states in India. *Indian Journal of Agricultural Economics*, 64(902-2016-66755).

48. O'Donoghue, E. (2014). The effects of premium subsidies on demand for crop insurance. *USDA-ERS economic research report*, (169).

49. Perez, N., Singh, V., Ringler, C., Xie, H., Zhu, T., Sutanudjaja, E.H. and Villholth, K.G., 2024. Ending groundwater overdraft without affecting food security. *Nature Sustainability*, *7*(8), pp.1007-1017.

50. Reddy, V. R. (2005). Costs of resource depletion externalities: a study of groundwater overexploitation in Andhra Pradesh, India. *Environment and development economics*, 10(4), 533-556.

51. Revesz, R. L. (2001). Federalism and environmental regulation: A public choice analysis. *Harv. L. Rev.*, *115*, 553.

52. Rouhi Rad, M., Araya, A., & Zambreski, Z. T. (2020). Downside risk of aquifer depletion. *Irrigation Science*, *38*(5), 577-591.

53. Schoengold, K., & Brozovic, N. (2018). The future of groundwater management in the high plains: evolving institutions, aquifers and regulations. In Western Economics Forum (Vol. 16, No. 1837-2018-2991, pp. 47-53).

54. Siebert, S., Burke, J., Faures, J. M., Frenken, K., Hoogeveen, J., Döll, P., & Portmann, F. T. (2010). Groundwater use for irrigation–a global inventory. *Hydrology and earth system sciences*, 14(10), 1863-1880.

55. Sims, C., Armsworth, P. R., Blackwood, J., Fitzpatrick, B., Kling, D. M., Lenhart, S., ... & Springborn, M. (2023). Leveraging federalism for flexible and robust management of social-ecological systems. *People and Nature*, *5*(2), 446-454.

56. Shepler, R., Suter, J. F., Manning, D. T., & Goemans, C. (2019). Private Actions and Preferences for Coordinated Groundwater Conservation in Colorado's Republican River Basin. *JAWRA Journal of the American Water Resources Association*, 55(3), 657-669.

57. Sheridan 6 LEMA. (2012) ORDER OF DECISION ACCEPTING THE SHERIDAN 6 LOCAL ENHANCED MANAGEMENT PLAN (PURSUANT TO K.S.A. 82a-1041(d)(1)). Accessed on May 16, 2022 at https://agriculture.ks.gov/divisions-programs/dwr/managing-kansas-water-resources/local-enhanced-management-areas/sheridan-county-6-lema

58. Shields, D. A. (2009). Federal crop insurance: Background and issues. Congressional Research Service, Library of Congress

59. Shiklomanov, I.A., Gleick, P. H. (1993). Water in crisis – World fresh water resources. *Pacific Institute for Studies in Dev., Environment & Security. Stockholm Env. Institute, Oxford Univ. Press. 473p*, *9*, 1051-0761.

60. Sloggy, M. R., Hrozencik, A., Manning, D. T., Goemans, C. G., & Claassen, R. L. (2025). Insurance and Extraction Incentives in a Common Pool Resource: Evidence from Groundwater Use in the High Plains. *Journal of Environmental Economics and Management*, 103125.

61. Smith, Steven M., et al. "Responding to a groundwater crisis: The effects of self-imposed economic incentives." *Journal of the Association of Environmental and Resource Economists* 4.4 (2017): 985-1023.

62. Summary of Business | RMA" https://www.rma.usda.gov/SummaryOfBusiness Retrieved 2022-01-21

63. Steiner, J. L., Devlin, D. L., Perkins, S., Aguilar, J. P., Golden, B., Santos, E. A., & Unruh, M. (2021). Policy, technology, and management options for water conservation in the Ogallala aquifer in Kansas, USA. *Water*, *13*(23), 3406.

64. Teets, J. C., Gao, M., Wysocki, M., & Ye, W. (2021). *The impact of environmental federalism: An analysis of watershed eco-compensation policy design in China. Environmental Policy and Governance*, 31(6), 580-591.

65. Tularam, G. A., & Krishna, M. (2009). *Long Term Consequences of Groundwater Pumping in Australia: A Review of Impacts Around the Globe.* Journal of Applied Sciences in Environmental Sanitation, 4(2).

66. U.S. Department of Agriculture, Risk Management Agency. (2021). *Prevented planting and Drought*. https://www.rma.usda.gov/about-crop-insurance/frequently-asked-questions/prevented-planting-drought

67. United States Geological Survey (2009). Estimated Use of Water in the United States in 2005, *U.S. Geological Survey Circular 1344*, October 2009

68. U.S. Geological Survey. (2018). Groundwater decline and depletion. U.S. Department of the Interior. https://www.usgs.gov/special-topics/water-science-school/science/groundwater-decline-and-depletion

69. Wang, Tong, Seong C. Park, and Hailong Jin. "Will farmers save water? A theoretical analysis of groundwater conservation policies." *Water Resources and Economics* 12 (2015): 27-39.

70. White, S. E., & Kromm, D. E. (1995). Local groundwater management effectiveness in the Colorado and Kansas Ogallala region. Natural Resources Journal, 275-307.

71. Wing, I. S., De Cian, E., & Mistry, M. N. (2021). Global vulnerability of crop yields to climate change. *Journal of Environmental Economics and Management*, *109*, 102462.

72. Woodard, J. D., & Verteramo-Chiu, L. J. (2017). Efficiency impacts of utilizing soil data in the pricing of the federal crop insurance program. *American Journal of Agricultural Economics*, *99*(3), 757-772.

73. Woodard, J. D. (2014). Impacts of weather and time horizon selection on crop insurance ratemaking: A conditional distribution approach. *North American Actuarial Journal*, *18*(2), 279-293.

74. Young, C. E., Vandeveer, M. L., & Schnepf, R. D. (2001). Production and price impacts of US crop insurance programs. *American Journal of Agricultural Economics*, *83*(5), 1196-1203.

75. Yu, J., & Sumner, D. A. (2018). Effects of subsidized crop insurance on crop choices. *Agricultural Economics*, *49*(4), 533-545.

76. Yu, J., Smith, A., & Sumner, D. A. (2018). Effects of crop insurance premium subsidies on crop acreage. *American Journal of Agricultural Economics*, *100*(1), 91-114.

77. Zektser, I. S. & Everett, L. G. (eds) Groundwater Resources of the World and Their Use (UNESCO, Paris, 2004); http://unesdoc.unesco.org/images/0013/001344/134433e.pdf.