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The Effects of Policy Implementation Uncertainty on Groundwater Extraction

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Abstract: Concerns about the high rate of depletion of the Ogallala Aquifer in the Southern High Plains of Texas (Texas High Plains) in recent years have led to the enactment of policies designed to slow down water extraction and increase the usable life of the aquifer. However, policy implementation has not been uniform across the aquifer, leaving some farmers in portions of the aquifer with no effective groundwater extraction restrictions only a short distance away from areas where farmers face regulatory limits. This study investigates the effects of policy implementation uncertainty on the extraction of groundwater. An econometric model is estimated for harvested acreage of the three major crops produced in the five representative counties of the Texas High Plains. Corn acreage (an irrigation-intensive crop) is used as a proxy for groundwater use. After controlling for price and climate effects, it was concluded that there is strong evidence that groundwater use policy uncertainty is likely to increase groundwater extraction in the Texas High Plains region. The social desire to achieve perpetual sustainability of groundwater resources in the study region, or at the very least to prolong the life of the Ogallala Aquifer, has resulted in discussions about alternative groundwater management policies. Producers, in their concern about the implementation of policies to slow down groundwater extraction, increase their use of water in the short-run in order to maximize profits before groundwater use restriction policies are enforced.

Keywords: *policy uncertainty, groundwater extraction, irrigation, agricultural productivity*

Over the past fifty years, demand for water resources in American agriculture has increased significantly. Irrigated agriculture currently uses between 80% and 90% of all consumptive water activity taking place in the United States (U.S.) (USDA ERS 2015). According to the 2008 Farm and Ranch Irrigation Survey, 74 million acre-feet (24 trillion gallons) of water are used annually for agricultural irrigation in the western states, and 48% of the water used is withdrawn from regional aquifers. These figures have been on the rise over the past few years (Schaible and Aillery 2012). The growing demand for water resources in agriculture has placed increased pressure on existing water sources and has induced an increased interest in water management, water conservation related issues, and the future sustainability of irrigated agriculture. Policies aimed at reducing water use and increased water resources conservation efforts have been adopted, and various technologies enhancing water use efficiency that directly contribute to improved sustainability of the water resources have been developed.

Agricultural irrigation has played a significant role in the economic growth and development of the Great Plains Region of the U.S. The Ogallala Aquifer (Figure 1) is the major source of irrigation water in this area, which includes 174,000 square miles. It lies beneath portions of eight states of the U.S.: Colorado, New Mexico, Wyoming, Texas, Kansas, Oklahoma, South Dakota, and Nebraska (Alley et al. 1999). Every year, almost 65% of the overall water used for irrigation in the U.S. is extracted from the Ogallala Aquifer. Furthermore, approximately 82% of the 2.3 million people who live in the Great Plains region acquire their drinking water from the Ogallala

Aquifer (Maupin and Barber 2005).

Intensive agricultural irrigation threatens the usable life of the Ogallala Aquifer (Dennehy et al. 2002). Daily groundwater use for irrigation from the Ogallala Aquifer has increased from 480 million cubic feet of groundwater in the early 1950s to 2,150 million cubic feet in 1980 (Alley et al. 1999). The decline of the water table across the region ranges from one-half foot to several feet per year. The Ogallala Aquifer is an unconfined aquifer, but when the rate of recharge is compared to the rate of extraction, the former is negligible (Birkenfeld 2003). The regional economy of the Great Plains depends on agricultural irrigation, but many people consider that the decline of groundwater of the Ogallala Aquifer is likely to play a potentially dramatic and significant negative role in the future (Terrell et al. 2002).

The southernmost portion of the aquifer – that which underlies the Texas High Plains (THP) – has experienced faster declines in groundwater because of the relatively low rate of recharge compared to the northern portion of the aquifer. In the southern portion of the aquifer, most people believe that recharge rates range from one-half inch to several inches per surface acre annually (High Plains Underground Water District No.1 2004). The ratio of extraction to recharge ranges from approximately 50:1 to as low as 1:1 (These estimates were extrapolated from changes in saturated thickness of the aquifer. Saturated thickness data was acquired from the Texas Tech University Center for Geospatial Technology: http://www.gis.ttu.edu/center/Ogallala/OgallalaData.html). Another study made a water use projection for the Texas Water Development Board using the Groundwater Availability Model for the Southern High Plains of Texas. They estimated the annual amount of water used for irrigation in the southern portion of the aquifer to be approximately 3,800,000 acre-feet, which

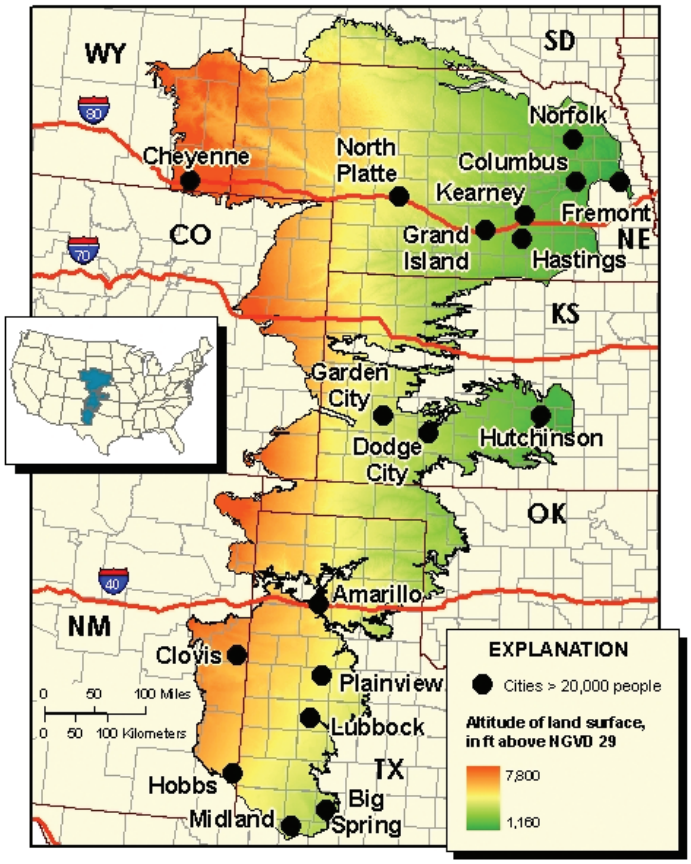

Figure 1. Location of the Ogallala Aquifer. Source: U.S. Geological Survey (USGS) http://ne.water.usgs.gov/ogw/hpwlms/.

is used to irrigate approximately 3,500,000 acres (Amosson et al. 2003). The main agricultural commodities produced in the southern portion of the Great Plains include wheat, grain sorghum, peanuts, corn, and cotton. This area accounts for a significant proportion of Texas agricultural crop production, including 26% of the production of grain sorghum, 46% of the production of wheat, 59% of the production of cotton, 40% of the production of peanut, and 10% of the production of corn (NASS 2006).

The future of agricultural production in the Southern High Plains of Texas, and the rural economies supported by it, depend in part on the future availability of groundwater. In order to slow down groundwater extraction and increase the usable life of the Ogallala Aquifer, several policies have been designed and implemented. However, policies have not been uniform across the aquifer, and in some counties local groundwater district's rules have not been enforced. To this end, public policy has been established which clarifies natural resource property rights and, in some cases, limits the private landowners' rights. In portions of the policy entitled "Rules of the High Plains Underground Water Conservation District No. 1" limitations of groundwater use for each year after 2012 are addressed. Specifically, producers are limited to apply up to 18 acre-inches per year in years 2014-2015 and up to 15 acre-inches beginning in 2016. However, these limits have yet to be enforced and these particular limits are not binding for most producers.

This study evaluates how policy implementation uncertainty (which means the policies are existing, expected to become increasingly binding, but not currently enforced) can impact groundwater extraction in the Texas High Plain area. Groundwater use policy implementation has not been uniform across the aquifer in the Texas High Plains, leaving some farmers in portions of the aquifer with no effective groundwater extraction policy only a short distance away from areas where farmers face regulatory limits on groundwater extraction. Farmers make decisions regarding what to produce to maximize their own profits. The market prices of the five crops and their relative irrigation requirements are the important factors that affect farmers' decisions. Moreover, the availability of groundwater in the Southern Ogallala Aquifer directly impacts the agricultural sector of the Texas High Plains. The optimal crop choice for each producer is constrained by this physical availability, and potentially further constrained by groundwater policy.

The specific objective of this study is to evaluate if uncertain or impending policies regarding irrigation water restrictions may actually cause farmers to withdraw more groundwater than in the absence of those expectations.

Literature Review

Irrigated farming activities in the Texas High Plains have led to a significant decline in the groundwater resources of the Ogallala Aquifer over the past 60 years. Decreased saturated thickness and increased depth to groundwater, combined with rising energy prices, has significantly increased farmers' pumping costs and decreased profits in recent years.

Surface water resources are nonexistent for the purpose of irrigated crop production in the Texas High Plains, therefore the Ogallala Aquifer is vital for irrigated agriculture to continue in the region. However, the capacity of the Ogallala Aquifer is limited, so, in order to preserve the economic life of the aquifer and maintain the viability of the regional economy which significantly depends on agriculture, water conservation policies need to be designed and implemented. The U.S. federal government encouraged farmers to develop irrigated agriculture as a way to increase revenues in the past, but the availability of the groundwater resources in the west of the U.S. has significantly declined in recent years. Therefore, government entities at various levels of aggregation have started to design policies with the purpose of conserving water (Wheeler 2008). For example, on September 1, 2005 the 79th Texas Legislature passed House Bill 1763, which requires, among other issues, that groundwater management areas around the state establish upper limits for groundwater extraction locally (Mace et al. 2006). It is anticipated that in the long-term, these factors will play an important role in the economic viability of agricultural irrigation in the

Texas High Plains (Taylor et al. 2007).

Agricultural producers in Texas, who utilize groundwater as the source of water for their irrigated operations, follow what is commonly known as the "right of capture" law (Terrell 1998). This law grants full property rights to landowners to use the groundwater extracted from beneath their land to their benefit (Kaiser and Skillern 2001). Falling groundwater tables – resulting in increased pumping lifts – combined with high energy prices in the late 1970s gradually caused reduction in groundwater yields, overall pumping, and consequently total area irrigated. In 2002, there were 3.5 million Texas High Plains' crop acres irrigated; this figure was about 55% lower than the number of acres irrigated in the late 1960s (Texas Senate Bill 2, Austin, TX, 2002).

In the late 1990s and early 2000s, the Texas legislation explicitly recognized the increasing scarcity of groundwater supplies, particularly Senate Bill 1 (Texas Senate Bill 1, Austin, TX, 1997) and Senate Bill 2 (Texas Senate Bill 2, Austin, TX, 2002). Senate Bill 1 (SB 1) modified several portions of Texas water law and modified the structure of the state water management modus operandi. It required the Texas Water Development Board (TWDB) to develop a comprehensive statewide water use plan that incorporated locally developed regional water plans (Article 1, Section 1.01). Senate Bill 2 (SB 2) established a Texas Water Advisory Committee, as well as a guide to improve surface water and groundwater management planning at the local, regional, and state levels (Texas Joint Committee on Water Resources 2002). SB 2 also increased the power of groundwater management districts over area within their jurisdiction, allowing them to carry out production charges to limit groundwater exploitation. This law explicitly stated that these costs cannot be more than one U.S. dollar per acre-foot of water extracted.

High Plains Underground Water Conservation District #1 Rules (HPWD1R) indicate that a "50/50 Management Goal" which means that 50% of the saturated thickness of the Ogallala Aquifer will need to be in the Ogallala Aquifer 50 years later would be desirable as a goal. The first planning interval of the 50/50 Management Goal started on January 1, 2010 and will end on January 1, 2060. Moreover, since January 1, 2012 all persons who own or operate a well or well system that withdraws groundwater from the Ogallala Aquifer are required to limit the total amount of water extracted from the well or well system. However, the High Plains Underground Water Conservation District #1 (HPUWCD1) extended moratoriums for the limit through 2014. Specifically, during their November 12, 2013 regular meeting, the HPUWCD1 Board of Directors voted 5-0 to extend current water extraction limit moratoriums in the district's rules through calendar year 2014 (Musico 2013).

Conceptual Framework

Following Beattie et al. (1985), this study assumes that a representative farmer in a given county will receive profits by producing different crops. In this study, the choice is limited to three crops – corn, cotton, and sorghum – because peanut and wheat production is not prevalent in the sub-area of the Texas High Plains that was the focus of our research. This can be shown by defining a profit function as:

$$\prod_j = TR_j - TC_j = \sum p_i * Q_{ij} - \sum r_k * x_{kj} - FC_j \quad (1)$$

where, $\prod_j$ represents profit in county j, TR_j represents total revenue in county j, TC_j represents total cost of production in county j, p_i represents price of crop i, Q_{ij} represents production of crop i in county j, r_k represents the price of input k, x_{kj} represents the quantity of input k used in county j, and FC_j is the fixed cost of production in county j. A supply function can be defined as:

$$Q_{ij} = A_{ij} * Y_i \quad (2)$$

where, A_{ij} is the number of acres planted of crop i in county j, and Y_i is the yield of crop i. Substitution of equation (2) into (1), results in an indirect profit function defined as:

$$\prod_j = \sum p_i * A_{ij} * Y_i - \sum r_k * x_{kj} - FC_j \quad (3)$$

It is assumed that farmers make their decisions regarding what to plant depending on several factors. These include time trend, price of crops, rainfall, and availability of groundwater. That is,

$$A_{ij} = f(t, p_i, r_k, R, G) \quad (4)$$

where, t represents time trend, p_i represents price

of crop i, R represents rainfall, and G represents availability of groundwater. Substituting (4) into (3) gives:

$$\prod_j = \sum p_i * Y_i * f(t, p_i, r_k, R, G) - \sum r_k * x_{kj} - FC_j \quad (5)$$

or more compactly,

$$\prod_j = \prod_j (t, p_i, r_k, R, G). \quad (6)$$

Given that the availability of groundwater for irrigation depends on the stock of water in the Ogallala Aquifer in the county and the existence of groundwater use policies, if it is assumed that the stock of water in the aquifer is sufficient enough for irrigation purposes then only the existence of groundwater use policies, or restrictions on groundwater withdrawals, influences the availability of groundwater use for irrigation. So, the indirect profit function can be rewritten as:

$$\prod_j = \prod_j (t, p_i, r_k, R, pol) \quad (7)$$

where, *pol* represents the existence of policies impacting groundwater use in the county. Beattie et al. (1985) also indicate that, following Hotelling's lemma, the partial derivative of the indirect profit function with respect to crop prices is equal to the supply equation:

$$\frac{\partial \prod_j}{\partial p_i} = Q_{ij.} \quad (8)$$

From equation (2) and (4), if Y_i is constant, then the supply function can be defined as:

$$Q_{ij} = f(t, p_i, r_k, R, pol) \quad (9)$$

where, $Q_{ij} = Y_i * A_{ij}$. Assuming that the cross price effects are equal across crops, and given that in this particular case the three crops analyzed will be cotton, corn, and sorghum, the following restrictions were added:

$$\frac{\partial Q_{corn}}{\partial p_{cotton}} = \frac{\partial Q_{cotton}}{\partial p_{corn}} \quad (10)$$

$$\frac{\partial Q_{corn}}{\partial p_{sorghum}} = \frac{\partial Q_{sorghum}}{\partial p_{corn}} \quad (11)$$

$$\frac{\partial Q_{sorghum}}{\partial p_{cotton}} = \frac{\partial Q_{cotton}}{\partial p_{sorghum}} \quad (12)$$

That is, the effect of cotton price on corn production is equal to the effect of corn price on cotton production; the effect of sorghum price on corn production is equal to the effect of corn price on sorghum production; and the effect of cotton price on sorghum production is equal to the effect of sorghum price on cotton production.

Methods and Procedures

As highlighted earlier, the purpose of this study is to estimate an econometric model to analyze how the uncertainty associated with the implementation of groundwater use polices can affect farmers' agricultural production decisions in the short run. Specifically, this study seeks to determine if the uncertain implementation or impending policy enforcement regarding irrigation water restrictions may actually induce farmers to withdraw more groundwater than in the absence of those expectations. This study assumes that farmers want to maximize their profits over time, so they have to make their decisions regarding input use with future input availability in mind. It follows that, if farmers anticipate a restriction in input use (groundwater in this case) in the future, they may intensify the use of that input in the current period. The yield response to applied water is positive and decreasing (∂yield / ∂irrigation > 0, ∂^2yield / ∂water^2 < 0) over the range of profit-maximizing water use, so farmers' input use decisions are revealed by the production of the crops. In other words; the level of output, the intensity of input use, and the crops produced reflect the inter-temporal profit-maximizing decisions farmers have made. The econometric model estimated here contains crop acreage as a function of a time trend variable (year), a yearly adjusted crop price variable, a yearly rainfall variable, and the existence of the policy regarding water use limitation variable (defined as a dummy variable). Corn, cotton, and sorghum have been the main crops produced in the research area in the past few decades. Corn is the crop that requires the most water for growth when compared with the other two crops. It is assumed that if increased amounts of water are used for irrigation this would lead to an increase in crop production. Conversely, if crop production changes are experienced, so this would directly reflect water use changes for irrigation, ceteris paribus.

Data were collected for 20 counties that are located within both the High Plains Underground Water Conservation District #1 and the Northern High Plains Underground Water Conservation District, both of which are located within the area comprising the Ogallala Aquifer in the Texas High Plains. As shown in Figure 2, the light blue area is the Northern High Plains Groundwater Conservation District, the orange area is the Panhandle Groundwater Conservation District, the green area is the Hemphill County Underground Water Conservation District, and the purple area is the High Plains Underground Water Conservation District #1. The majority of the data used was obtained from the National Agricultural Statistics Service (NASS 2006). However, data availability required the study to be restricted to only five counties within the High Plains Underground Water Conservation District #1. These five countries included Deaf Smith, Parmer, Castro, Hale, and Floyd (shown in Figure 1 and Figure 2). Through direct observation of the data gathered, these five counties produce corn, cotton, and sorghum. The corn acreage within these five counties comprises the majority of the corn acreage grown in the entire Texas High Plains area. Table 1 presents the average acres of each crop planted, by county, over the study period of 1991 through 2013.

The current High Plains Underground Water Conservation District #1's groundwater use restrictions have never been enforced, but irrigators have the expectation that enforcement of this policy is quite likely in the future. It is hypothesized that producers who expect to face future production losses and lower revenues due to the enforcement of water limiting use policies will use as much

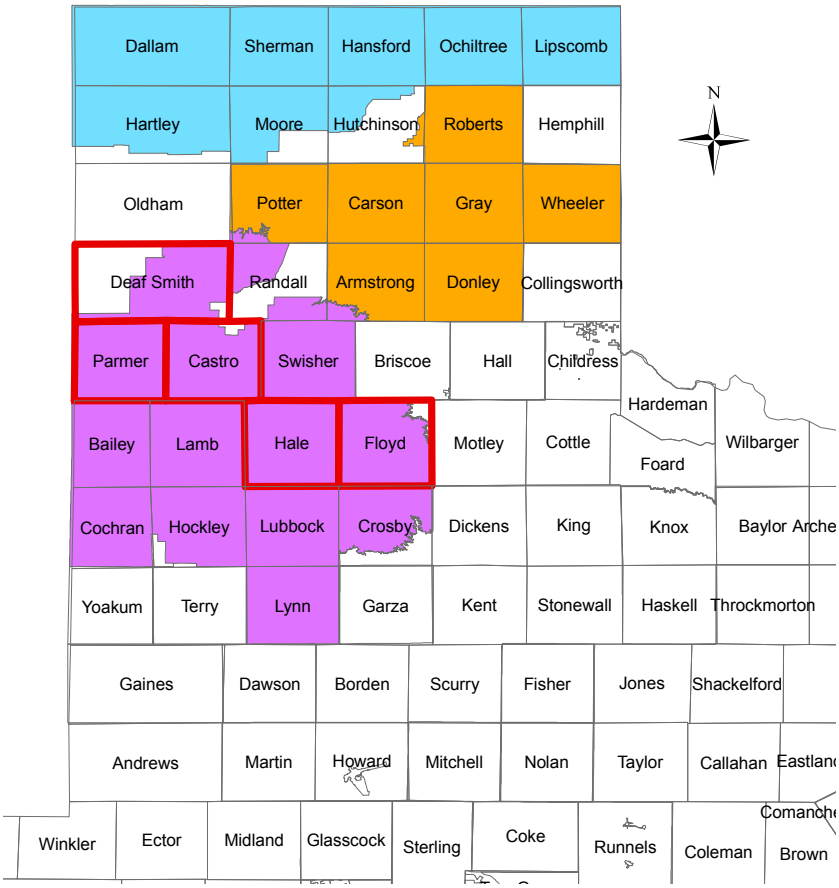

Figure 2. Location of Texas counties analyzed (outlined on map). Analyzed counties (Deaf Smith, Parmer, Castro, Hale, and Floyd) are within the High Plains Underground Water Conservation District #1. Source: Texas Water Development Board http://www.twdb.texas.gov/mapping/gisdata.asp.

Table 1. Average acreage of crops planted for each county.

County	Corn Acres Planted	Cotton Acres Planted	Irrigated Cotton Acres Planted	Non-irrigated Cotton Acres Planted	Sorghum Acres Planted	Irrigated Sorghum Acres Planted	Non-irrigated Sorghum Acres Planted
Castro	102,234	62,956	60,820	2,136	27,686	17,278	10,407
Deaf Smith	37,991	25,960	18,426	7,534	77,913	31,880	46,033
Parmer	75,652	66,704	62,747	3,956	44,108	23,340	20,767
Hale	49,743	243,960	213,260	30,700	45,900	33,761	12,138
Floyd	14,052	184,617	126,495	58,121	41,818	24,910	16,908
Swisher	19,247	82,078	63,891	18,187	38,861	20,042	18,819
Total	298,919	666,275	545,639	120,634	276,286	151,211	125,072

water as they can now to increase current profits. In order to test this hypothesis, this study uses a representative crop production regression model for the five counties (modeling the five counties as a profit-maximizing producer), and this model is estimated using seemingly unrelated regression (SUR) methods to analyze how the existence of the policy, crop prices, and climate affect crop production. Given that corn, cotton, and sorghum are the three main crops produced in the five counties analyzed, this study uses acres harvested for each crop as its dependent variable reflecting the level of crop production. Additional crops, as well as additional inputs to the production process, could be included in the analysis using an index approach, but such analysis is beyond the scope of this study. Three separate linear supply equations (which represent the first derivatives of an unspecified normalized quadratic profit function) for each crop in the five counties were estimated.

As highlighted above, SUR procedures were followed in the estimation of the regression model. The SUR system for the five counties includes three individual relationships that are linked by the fact that their disturbance terms are correlated (price of corn, cotton, and sorghum). The correlations among the disturbance terms could come from several sources, including crop prices. Thus, in this case, there is a need to include constraints linking restrictions on the parameters across the different equations for given counties. On the other hand, equations explaining some phenomenon in the counties selected provide a natural application as these various factors are likely to be subject to spillovers from farm level or county level shocks.

There are two main motivations for the use of SUR in this study. First, this study proposes to gain efficiency in estimation by combining information on different equations. The second motivation is to impose restrictions that involve parameters in different equations. SUR provides an appropriate model and can clearly demonstrate the relationship of each observation in this study.

The functions specified for each of the five counties included in the estimation are:

$$\textit{Corn Acres Harvested} = f(\textit{year, rainfall, policy, corn adjusted price, cotton adjusted price, sorghum adjusted price}) \quad (13)$$

$$\textit{Cotton Acres Harvested} = f(\textit{year, rainfall, policy, corn adjusted price, cotton adjusted price, sorghum adjusted price}) \quad (14)$$

$$\textit{Sorghum Acres Harvested} = f(\textit{year, rainfall, policy, corn adjusted price, cotton adjusted price, sorghum adjusted price}) \quad (15)$$

The adjusted commodity prices are calculated by dividing the specific commodity price received in one year divided by the prices received index for the prior year. The prices received index is an index of all prices received for crops and livestock, with the base being 1990 - 1992 = 100.

In order to protect the stock of groundwater in the Ogallala Aquifer, policies have been crafted to limit its use. In this case, for the High Plains Underground Water Conservation District #1, the existence of the groundwater use limitation policy restriction was specified as a dummy variable: 0

reflecting no policy for groundwater use is in place, and a 1 reflecting the existence of the policy (years 2010 through 2013), but unenforced, limiting groundwater use. The model to be estimated will support the hypothesis in the affirmative if the estimated parameter associated with the policy variable in the corn supply equation is positive and significant; where a positive and significant policy variable would indicate that corn acreage would be expected to increase due to the introduction of the unenforced policy. This would support the hypothesis as stated because corn is the most water-intensive crop among all crops considered, and an increase in corn acreage would be directly associated with an increase in total groundwater use/extracted from the aquifer.

Results

The result of the SUR analysis for Hale County is presented in Table 2. Data for the analysis encompasses the years of 1991 through 2013. The policy dummy variable takes a value of 1 for the years 2010 through 2013. The estimated parameter on the policy variable in the corn supply equation is positive and statistically significant. This result supports the hypothesis that when the unenforced policy is in place corn acreage and, consequently, groundwater usage increase. Similar results are found for each of the counties in the study area. The parameter estimates for the *policy* variable from each of the county level crop production models, along with their associated p-values, are presented in Table 3. In addition, the table provides the average acres of corn harvested for the period 1991 through 2009, prior to the implementation of the groundwater policy.

The results presented in Table 3 are both statistically significant and significant in their magnitudes. The change in the acres of corn production, by county, represent a meaningful increase relative to the average corn production prior to the policy implementation. The optimal levels of groundwater application for the irrigation of corn, cotton, and sorghum are assumed to be 21.80 inches, 9.86 inches, and 8.73 inches per acre, respectively (Turner et al. 2011). Therefore, if producers switch acres from cotton or sorghum to corn, the resulting change in water withdrawals would be expected to be approximately ten inches per acre. A ten acre-inch increase in irrigation for each of those additional acres of corn production contributes significantly to the annual drawdown of the Ogallala Aquifer.

Table 4 provides the results of a SUR model using the aggregate data from the five county study

Table 2. Regression parameters for crop production models, Hale County, Texas (1991 – 2013).

	Constant	Year	Rainfall	Policy	Adjusted Corn Price Received	Adjusted Cotton Price Received	Adjusted Sorghum Price Received
Corn Acres Harvested	7,805,467 (0.000)*	-3,922 (0.000)	1,130 (0.051)	20,416 (0.035)	89,596 (0.000)	-70,429 (0.022)	-31,864 (0.037)
Cotton Acres Harvested	-8,691,431 (0.030)	4,529 (0.024)	1,047 (0.575)	-31,483 (0.331)	-70,429 (0.022)	230,319 (0.003)	-30,935 (0.197)
Sorghum Acres Harvested	378,279 (0.857)	-1,850 (0.859)	-1,072 (0.334)	-10,601 (0.593)	-31,864 (0.037)	-30,935 (0.197)	38,558 (0.003)

* Probability value associated with parameter.

Restriction:

(1) [corn acres harvested] adjusted sorghum price received - [sorghum acres harvested] adjusted corn price received = 0

(2) [corn acres harvested] adjusted cotton price received - [cotton acres harvested] adjusted corn price received = 0

(3) [cotton acres harvested] adjusted sorghum price received - [sorghum acres harvested] adjusted cotton price received = 0

Table 3. Policy parameter estimate for corn acres harvested in county-level SUR regressions with associated p-values and historic corn acres harvested.

County	Policy Parameter Estimate	P-value	Average Corn Acres Harvested 1991-2009	Average Corn Acres Harvested 2010-2013
Castro	15,666	0.140	86,568	97,275
Deaf Smith	14,063	0.017	29,321	29,675
Parmer	21,460	0.069	62,578	50,950
Hale	20,416	0.035	45,910	38,275
Floyd	7,736	0.031	11,426	11,988

area, and we provide a matrix of error correlations for the model in Table 5. Here, the policy variable is not statistically significant in the corn supply equation. However, it is statistically significant in the sorghum supply equation where the parameter estimate is negative. Sorghum has the lowest crop water requirement of the three in the model, so acreage leaving sorghum production to either corn or cotton reflects an increase in groundwater usage. Heterogeneity across acres in the study area influences to which of the two crops an individual producer will switch. The sorghum variable is the only one that is statistically significant because, in the aggregate, some acreage moves to corn and some moves to cotton (not all producers have access to sufficient water to make the transition to corn). The specific transitions are largely a function of geographic location, so when averaged across the study area we find that the estimated changes in corn acres and cotton acres are not statistically significant.

These results again support the hypothesis stated above, that the uncertainty associated with the implementation of groundwater use policy indeed would affect farmers' agricultural production decisions. Specifically, uncertain or impending adoption of policies restricting groundwater use for irrigation is found to cause farmers to withdraw more groundwater than in the absence of those potential restrictions.

By using the optimal irrigation rates from Turner et al. (2011), and adjusting average groundwater use for cotton and sorghum production to account for both irrigated and non-irrigated cotton and sorghum acreages used in this study, we are able to estimate the groundwater extraction changes resulting from the policy implementation. These calculations are made as follows:

For corn:

$$\textit{Groundwater Use Change for Corn} = app_{cor} * \textit{policy of corn} \quad (16)$$

where, app_{cor} represents groundwater application for the irrigation of corn.

For cotton:

$$\textit{Adjusted Average Groundwater Use for Cotton} = \textit{irrigated cotton acres planted} * app_{cot} / \textit{cotton acres planted} \quad (17)$$

$$\textit{Groundwater Use Change for Cotton} = (17) * \textit{policy of cotton} \quad (18)$$

where, app_{cot} represents groundwater application for the irrigation of cotton.

For sorghum:

$$\textit{Adjusted Average Groundwater Use for Sorghum} = \textit{irrigated sorghum acres planted} * app_{sor} / \textit{sorghum acres planted} \quad (19)$$

$$\textit{Groundwater Use Change for Sorghum} = (19) * \textit{policy of sorghum} \quad (20)$$

where, app_{sor} represents groundwater application for the irrigation of sorghum.

By performing the calculations highlighted above, the following result is obtained. The predicted increase in groundwater use for irrigation across the three crops over the entire area is a total of 1,041,440 acre-inches. Given that the actual amount of groundwater use without the policy in place is 11,991,990 acre-inches, the existence of the policy – without enforcement – results in an estimated increase of 8.68% on groundwater use in the five counties.

Table 4. Regression parameters for crop production models for the research area.

	Constant	Year	Rainfall	Policy	Adjusted Corn Price Received	Adjusted Cotton Price Received	Adjusted Sorghum Price Received
Corn Acres Harvested	2.57e+07 (0.000)*	-12,915 (0.000)	6,855 (0.006)	51,084 (0.264)	195,874 (0.001)	-85,099 (0.153)	-81,254 (0.019)
Cotton Acres Harvested	-1.89e+07 (0.053)	9,940 (0.042)	1,367 (0.772)	67,746 (0.421)	-85,099 (0.153)	248,457 (0.034)	-52,870 (0.173)
Sorghum Acres Harvested	6,732,761 (0.214)	-3,355 (0.216)	781 (0.799)	-129,246 (0.016)	-81,254 (0.019)	-52,870 (0.173)	83,266 (0.001)

* Probability value associated with parameter.

Restriction:

(1) [corn acres harvested] adjusted sorghum price received - [sorghum acres harvested] adjusted corn price received = 0

(2) [corn acres harvested] adjusted cotton price received - [cotton acres harvested] adjusted corn price received = 0

(3) [cotton acres harvested] adjusted sorghum price received - [sorghum acres harvested] adjusted cotton price received = 0

Table 5. Correlation matrix of residuals.

	Corn Acres Harvested	Cotton Acres Harvested	Sorghum Acres Harvested
Corn Acres Harvested	1.00	--	--
Cotton Acres Harvested	-0.108	1.00	--
Sorghum Acres Harvested	-0.1985	-0.6708	1.00

Breusch-Pagan test of independence: Pr = 0.0092.

Conclusion

This study determines if uncertain or impending policy enforcement regarding irrigation water restrictions may actually induce farmers to withdraw more groundwater than in the absence of those expectations. This study (1) constructs a crop production yield econometric model to determine the relationship among selected factors, and analyzes how several independent variables affect the dependent variables included (crop acreages), and (2) tests if and how existing policies of groundwater use in the Ogallala Aquifer affect irrigation decisions and groundwater extraction levels.

The results of this study show that when the groundwater restriction policy is in place, farmers are likely to produce more corn than the other two major crops considered. This implies that the number of corn acres and cotton acres are likely to increase under the presence of the water use policy restriction, and grain sorghum acres would be expected to decrease. Groundwater use would be expected to increase as a result because corn requires more water than cotton for growth, and cotton requires more water than sorghum for growth. Based on these results, uncertainty in groundwater use restriction policy or imminent enforcement of such policy was found to indeed affect farmers' agricultural production decisions. That is, uncertain or impending policy implementation enforcement regarding irrigation groundwater restrictions is found to actually induce agricultural producers to withdraw more groundwater than in the absence of those restrictions. The enactment of specific policies, when not enforced, may lead to unintended consequences. In this particular case, a policy intended to curb groundwater withdrawals

from the Ogallala Aquifer is actually associated with the acceleration of groundwater withdrawals.

Specific conclusions for the Texas High Plains from this study include: (1) uncertainty regarding the enforcement of groundwater use limits can lead (and indeed *has* led in recent years) to exactly the opposite result, increased groundwater use, initially intended by the policy in the first place, and (2) decision makers must be aware that when evaluating the potential impacts of groundwater use policies, the evaluation and estimation of the impacts using aggregate (region-wide) versus disaggregate (county-wide) estimates can lead to overestimation or underestimation of total groundwater use.

The main limitation of this study is that the results obtained here are deemed to be applicable only in the "short run" because no alternative crops were considered in the analysis. Future research could explore the impact on crop choice induced by the short run increase in water usage. Additionally, this study focused on the entire research area (the five counties) and the general directional response. This does not provide policy makers with an understanding of why there were differential responses, in terms of magnitude, across the counties. Potential future work would identify the county level characteristics, or perhaps the individual producer characteristics, that are correlated with increased water use in the face of an unenforced groundwater extraction quota.

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References

Alley, W.M., T.E. Reilly, and O.L. Franke. 1999. Sustainability of ground-water resources. *U.S. Geological Survey Circular 1186.* Available at http://pubs.usgs.gov/circ/circ1186/. Accessed June 21, 2016.

Amosson, S., T. Marek, L. New, F. Bretz, and L. Almas. 2003. Estimated irrigation demand for the southern Ogallala GAM. Available at https://www.twdb.texas.gov/publications/reports/contracted_reports/doc/2001483379_AppendixB.pdf. Accessed June 21, 2016.

Beattie, B.T., C.T. Taylor, and M.J. Watts. 2009. *The Economics of Production*, 2nd ed. Krieger Publishing Company, Malabar, FL.

Birkenfeld, D. 2003. Reclaiming water as a commons. *Southwest Chronicle* 4: 1-4.

Dennehy, K.F., D.W. Litke, and P.B. McMahon. 2002. The High Plains Aquifer, USA: Groundwater development and sustainability. *Geological*

Society, *London, Special Publications* 193: 99-119.

High Plains Underground Water District No.1. 2004. The Ogallala Aquifer. Available at http://www.hpwd.org/. Accessed June 21, 2016.

Kaiser, R.A. and F.F. Skillern. 2001. Deep trouble: Options for managing the hidden threats of aquifer depletion in Texas. *Texas Tech Law Review* 32: 249-304.

Mace, R.E., R. Petrossian, R. Bradley, and W.F. III Mullican. 2006. A streetcar named desired conditions: The new groundwater availability for Texas. In State Bar of Texas 7th Annual the Changing Face of Water Rights in Texas, 18-19 May, San Antonio, TX.

Maupin, M.A. and N.L. Barber. 2005. Estimated withdrawals from principal aquifers in the United States, 2000. *U.S. Geological Survey Circular 1279*.

Musico, J. 2013. Water district board extends moratorium for penalties on certain water use. *Lubbock Avalanche-Journal Lubbock Online,* Lubbock, TX.

National Agricultural Statistics Service. 2006. Quick Stats: Agricultural Statistics Data Base. Available at http://www.nass.usda.gov/Quick_Stats. Accessed June 21, 2016.

Schaible, G.D. and M.P. Aillery. 2012. Water conservation in irrigated agriculture: Trends and challenges in the face of emerging demands. EIB-99, U.S. Department of Agriculture, Economic Research Service.

Taylor, R.H., L.K. Almas, and W.A. Colette. 2007. Economic analysis of water conservation policies in the Texas Panhandle. Selected paper prepared for Southern Agricultural Economics Association Annual Meeting, Mobile, AL, 4-7 February.

Terrell, B.L., P.N. Johnson, and E. Segarra. 2002. Ogallala Aquifer depletion: Economic impact on the Texas High Plains. *Water Policy* 4: 33-46.

Terrell, B. 1998. Economic impacts of the depletion of the Ogallala Aquifer: An application to the Texas High Plains. Unpublished MS thesis, Texas Tech University, Lubbock, Texas.

Texas Senate Bill 1, Austin, TX, 1997. Available at http://www.twdb.texas.gov/waterplanning/swp/1997/. Accessed February 4, 2009.

Texas Senate Bill 2, Austin, TX, 2002. Available at http://www.twdb.texas.gov/waterplanning/swp/2002/index.asp. Accessed February 4, 2009.

The Texas Joint Committee on Water Resources, 2002. Texas Joint Committee on Water Resources report to the 78th Legislature. Available at http://www.senate.state.tx.us/75r/Senate/commit/c895/Downloads/water.pdf. Accessed June 21, 2016.

Turner, C.G., K. McAfee, S. Pandey, and A. Sunley. 2011. Irrigation metering and water use estimates: A comparative analysis, 1999–2007. *Texas Water Development Board*, Report 378, July.

USDA ERS. Irrigation Water Use. *Ers.usda.gov*. Last modified Thursday, October 08, 2015. Available at http://www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use.aspx. Accessed June 21, 2016.

Wheeler, E.A. 2008. Water conservation reserve program alternatives for the southern Ogallala Aquifer. Dissertation, Texas Tech University, Lubbock, Texas.