Effects From a Farmer-led Collective Action Water Management Plan on Irrigators in Kansas

Krystal M. Drysdale, Kansas State University, kmd123@ksu.edu
Nathan P. Hendricks, Kansas State University, nph@ksu.edu

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Water security in the future faces substantial challenges due to increasing demands from population growth, agricultural production, urban development and climate change. This drives the necessity for states and local communities to provide leadership and enactment of policies to extend the availability of water resources, restore watersheds and invest in programs and management strategies that contribute to reversing the growing water crises across the US (Department of the Interior, 2015). Defining specific water policy directives for water quality or quantity issues can be difficult with various stakeholders having opposing points of interest. In this study, we examine the effects on irrigators' behavior of a local effort initiated by farmers to reduce irrigation withdrawals from a small region in the High Plains Aquifer.

Depleting groundwater resources has become a crucial topic across the U.S. and continues to be at the forefront of agricultural research. The High Plains Aquifer is the largest groundwater storage reservoir in the US covering 174,000 square miles (110 million acres) of the Great Plains and stretching across eight states (McGuire, 2002). Currently the aquifer has an annual recharge rate of less than an inch a year making it essentially a nonrenewable resource and due to the common-pool nature of the Aquifer, individual water users do not pay the social cost of extracting groundwater (Hornbeck and Keskin, 2014).

Concerns about depleted aquifers for agricultural production are not unique to the Great Plains. Groundwater extraction for irrigation provides a substantial increase in crop yields and stabilizes profits due to uncertain weather; however, using data from NASA's GRACE satellite, Famiglietti (2014) found that groundwater is being depleted in the largest global agricultural zones which could decrease crop production and subsequently raise food prices. In response to the growing concern over appropriate management of the aquifer farmers in Sheridan County, Kansas voted to impose restrictions on themselves by forming a Local Enhanced Management Area (LEMA) in an effort to self-regulate their water use.

Ostrom (2009) described factors that lead to collective action indicating that users of a resource will invest their time and energy and self-organize to avert a tragedy of the commons when it becomes profitable to do so, such that the expected benefits exceed the perceived costs of regulations. Although joint benefits may be established between users, self-organizing to sustain a resource increases time burdens for the users and could result in a loss of short-term economic gains causing users to avoid these costly changes and continue to overuse the resource. Farmers will be more likely to pursue these collective action efforts to the extent that they can adapt to water restrictions and offset the short run negative impacts. Our results give some insights into the adaptation strategies pursued by farmers.

The focus of our research is to consider impacts from the collective action water quantity restriction policy implemented in Sheridan County, Kansas. We use difference-in-difference estimators to compare changes in irrigation behavior inside the policy boundary to behavior in a 5 mile buffer zone outside the policy boundary. We estimate the effect of the policy on total water use, irrigated acreage, water intensity, and cropping patterns. Our results give new insights into how irrigators adjusted their behavior to adapt to the restriction in the short run. By understanding the different margins of adjustment our results also indicate the potential effect of water restrictions on other agribusiness industries due to changes in agricultural outputs and inputs.

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Because our particular water use policy is not tied to county boundaries but rather to areas identified with critical concerns, it is necessary to describe the policy restriction beyond the county level. Hendricks and Peterson (2012) found few water management studies utilizing microdata with the exception of Moore et al. (1994) and Schoengold et al. (2006). Additionally we find little literature estimating the response of irrigators to a quantity restriction, with two exceptions. Johansson et al. (2002) assessed quantity regulations on the share of water resources and estimated of the "value" of water. Golden and Leatherman (2011) produced a study considering groundwater demand and revenue loss effects on crop production by comparing before and after trends of a water quota policy in an effort to evaluate effects on irrigator's profits. They concluded that the localized policy resulted in significant reductions in total area groundwater use, a positive effect on the life of the aquifer, but insignificant long run effects on annual irrigated crop revenues.

A large portion of the policy literature that addresses irrigated users is dedicated to effects of water pricing variation (Green et al. 1996; Varela-Ortega et al. 1998; Gomez-Limon et al. 2002; Gomez-Limon & Riesgo 2004; Scheierling et al. 2006; Inglesias & Blanco 2008). These studies address important questions related to the elasticity of water demand and model crop irrigation/production functions and willingness to pay/water rents. Other studies have estimated response of water use to changes in the price of water for field crops including Moore et al. (1994), Schoengold et al. (2006), Iglesias and Blanco (2008), and Hendricks & Peterson (2012).

A more recent study by Hornbeck and Keskin (2014) considered direct effects on irrigation strategy, drought risk, land values and crop type from variations in water availability over the High Plains Aquifer but again, this analysis was based on county-level data from the US Census of Agriculture. The research design in Hornbeck & Keskin (2014) does; however, describe spatially High Plains Aquifer groundwater shares, comparing counties over the High Plains Aquifer with nearby similar counties while controlling for average differences in soil characteristics and weather and provides a useful framework to assess differences across neighboring counties over the aquifer.

Our policy instrument is a relatively new initiative established in 2012 such that there is insufficient time series data to mirror Hornbeck & Keskin's methods for modeling adaptation in the long run; however, this study is conceptually similar in comparing differences between restricted farmers to those located outside the LEMA water restriction area. Our analysis only allows us to estimate the short term production decision changes due to the LEMA water use restriction.

Our estimates indicate that the collective action management plan was successful at reducing groundwater use. We find the largest response to the water restriction policy occurred at the intensive margin such that irrigators primarily responded by reducing the number of applied inches of water per acre; however, we also find that irrigators subject to the water use restriction responded by shrinking the total number of irrigated acres. We find some irrigators within the water restriction policy boundary switched from high water intensity crops to crops with less water demand. In general, we find irrigators adjusted water use primarily by reducing irrigation intensity on corn or soybean rather than switching to different crops.

Background on the Sheridan 6 LEMA

In 2012, new legislation granted Kansas Groundwater Management Districts (GMDs) the power to originate their own localized water conservation management plans which are then legally enforced by the state (Kansas Dept. of Agriculture, 2013).(). Farmers in Sheridan County, located in the northwestern corner of Kansas were the first to impose restrictions on themselves by forming a Local Enhanced Management Area (LEMA) in 2013 as a collective action effort to regulate their water use.

As described by the order of the Chief Engineer, the overarching goal of the LEMA is a collective action to restrict irrigated groundwater rights to no more than 114,000 acre-feet total over January 1, 2013, and December 31, 2017, in a manner that preserves the economic benefits of irrigation further into the future. The 99 square mile area maintains 185 wells for irrigation and 10 non-irrigation wells and puts in place the goal of reducing groundwater pumping by approximately 20% whereby restricting irrigators to a five-year allocation of 55 inches each (LEMA Sheridan 6 Order of Designation, 2013). .

The water management plan is of interest to many due to its uncommon collective action establishment in the interest of extending the life of the aquifer. The boundaries contained within the LEMA are defined by critical groundwater conditions and discussions about new LEMA enactment are currently being initiated in GMDs across the state including 4 additional areas in Sherman County, five west-central counties (GMD 1), and 12 south-west counties (GMD 3) suggesting more farmers will be under these quantity restrictive policies in the near future.

The LEMA could impact farmers' profitability, causing them to modify other inputs such as agricultural equipment, storage decisions, pesticide management, or nutrient management. As noted by a farmer in support of the proposal when questioned about how the water restriction might impact his profits, he replied, "We'll probably net more (profits)…" Many farmers who spoke out in support of the LEMA indicated that they felt that the LEMA provided enough flexibility in water allocation from year to year such that farmers would capitalize on their abilities to adapt and could actually be more profitable allowing future generations to continue irrigation practices. This did not come without criticisms; however, with other farmers pointing out possible disproportionate water use based on unequal water right allocation between farmers within the restricted boundaries and a possible result of increased water use due to unlimited flexibility of allocation between water rights and unlimited well locations. Some argued this gives farmers the ability to purchase additional water rights to irrigate their present place of use causing potential for more water use than before the LEMA (LEMA Sheridan 6 Order of Designation, 2013).

In this study, we estimate the impact of the Sheridan County 6 LEMA irrigation intensity, crop type and technology adoption to uncover adaptation strategies adopted by farmers. In addition, our study will validate if the water restriction achieved the intended purpose of reducing irrigation withdrawals. The results from this study will help to broaden our understanding of the effects from this localized restrictive policy and subsequent implications on future water policy management initiatives across the US. Global considerations of depleted groundwater resources has become of greater concern and initiatives such as the Sheridan County 6 LEMA could offer alternative strategies for effective resource management through a common action management plan led by farmers and legally enforceable by the state.

Conceptual Model

The studies conducted by Moore et al. (1994) and Schoengold et al. (2006) decompose the elasticity into extensive and intensive marginal effects indicating that if most of the price response is at the intensive margin, then policies that target irrigation intensity or water saving technologies will be more effective. We conceptually model the effect of the collective action LEMA on acreage planted to different crops, the adoption of more efficient irrigation technologies and irrigation intensity as different margins of adjustment similar to the study conducted by Hendricks and Peterson (2012) which evaluated marginal effects of price changes. Here we apply the same methodology to responses from a water quantity restriction from the Sheridan 6 LEMA.

Extensive and Intensive Marginal Effects

We decompose the effect of the quantity restriction into the following three direct and indirect margins of adjustment: (i) extensive (irrigated acreage), (ii) indirect intensive (changes in crop allocation), and (iii) direct intensive (changes in irrigation intensity for a given crop). Our decomposition follows the same methodology as used in the water demand literature that examines the margins of adjustment to changes in price (Hendricks and Peterson 2012; Schoengold et al. 2006; Moore et al. 1994).

Assume we have a representative irrigator such that their water demand for a particular well is subject to a water quota denoted q. We identify a particular land use as the varying combination of crop type and irrigation technology and represented as $j = 1, \dots, J$ land uses. Let irrigators choose $a(q)$ the optimal irrigated acreage, and let $w_j(q)$ indicate the optimal applied water intensity in acre inches/acre for each of the j land uses. Let $s_j(q)$ represent the optimal share of irrigated acreage for each land use. We define the average applied water per acre as:

$$w(q) = \sum_{j=1}^{J} s_j(q)\, w_j(q)$$

Here we are only interested in modeling water demand as a function of the LEMA water quota restriction. We represent total water use at the field level as a function of the total quantity of irrigated water and written as a function of average applied water per acre multiplied by the number of acres irrigated:

$$D(q) = w(q)a(q)$$

We can differentiate the above equation and multiply by $q/D(q)$ to yield the extensive marginal effects such that we can identify the expansion in irrigated acres $\mu_{a(q)}$ and the total intensive marginal effect, the change in irrigation intensity $\mu_{w(q)}$ due to a change in the water quota of the LEMA and represent the elasticities:

$$D'(q)\frac{q}{D(q)} = w'(q)\frac{q}{w(q)} + (q)\frac{q}{a(q)}$$

or more simply

$$\mu_{D(q)} = \mu_{w(q)} + \mu_{a(q)}$$

Additionally we can find from decomposition of the average applied water per acre function $w(q)$ the direct and indirect intensive marginal effects or the changes in crop allocation due to a change in the water quota of the LEMA. We begin by differentiating $w(q)$ and multiply by $q/w(q)$ such that:

$$\mu_{w(q)} = \left[\sum_{j=1}^{J} s_j(q)\, w_j'(q) + \sum_{j=1}^{J} s'_j(q)\, w_j(q)\right]\frac{q}{w(q)}$$

or rather

$$\mu_{w(q)} = \mu_{ww} + \mu_{ws}$$

Here we find the total intensive margin is made up of two effects μ_{ww} which can be described as the direct intensive marginal effect and μ_{ws} defined as the indirect intensive marginal effect. The indirect marginal effect identifies the change in water intensity because farmers switch to less water intensive crops. The direct intensive effect identifies changes in water intensity due to less water application per acre while holding constant the cropping pattern.

Data

Our proposed analysis will merge spatial datasets to describe the effects on farmers' decisions from LEMA. Because LEMAs are not tied to county boundaries but rather to areas identified with critical concerns, we identify the variables in our model for water withdrawal, crop type and irrigation system from the Water Rights Information System Database (WRIS). Kansas law requires all water right holders to report annually on irrigation and crop characteristics (Hendricks and Peterson, 2012).

Each well (termed a "point of diversion") in our sample group was identified spatially and taken from (WRIS) and used as our identifier for crop and irrigation decisions. Our study uses an unbalanced panel across a 5 year period (2009-2013) using points of diversion insides the LEMA boundary and points of diversion in a 5 mile buffer outside the LEMA boundary. Points of diversion subject to the LEMA quantity restriction were identified from official Kansas Department of Agriculture data. We also construct a 5 mile buffer zone surrounding the LEMA to use as the control group for which we base a Difference-in-Differences (D-I-D) fixed effect model to evaluate the causal effect from farmers being subject to the LEMA. .

The specific crops considered in this analysis include alfalfa, corn, sorghum, soybeans, and wheat with two additional categories identified as multiple and other. The category for other irrigated uses includes fruits, vegetables, sunflowers, golf courses, pasture, cotton, athletic fields, turf grass, barley, oats, rye, and dry beans. Additionally some reporting merely indicates that "multiple" crops were grown, but not which crops were specifically grown. The Kansas data does not indicate the number of acres planted to each crop nor how the irrigated water was distributed to each crop when multiple crop types were reported. We follow the methodology of Hendricks and Peterson (2012) to identify that if k crops were grown, the proportion of the field in each crop is simply $1/k$. The irrigation technologies in our analysis include flood, drip, center pivot, center pivot with low drop nozzles, and other sprinkler types.

Empirical Model

Difference-In-Differences

We use difference-in-differences to evaluate the difference the short run effect of the LEMA on farmers' water use behavior. Difference-in-differences controls for unobserved heterogeneity of fields that are constant over time and unobserved heterogeneity of each year that are constant across fields. Consider a vector of on-farm choice variables (Y_{0ilt}) made by an irrigator i for a particular well where in the absence of the LEMA, the irrigator's on farm decisions are determined by the sum of a time-invariant LEMA effect (α_l) and a yearly effect captured by (δ_t) that is common across *all* irrigators. The choice variables for each irrigator include ($\ln(a_i)$) log acres irrigated, ($\ln(w_i)$) log of water intensity, and proportion planted to each (c_i) crop type. We represent the potential outcome of not being subject to the LEMA, (i.e. the untreated group) as an expectation that is assumed to be constant over time:

$$E[Y_{0ilt}|l,t] = \alpha_l + \delta_t$$

where:

$Y = a\ vector\ of\ outcome\ variables$
$l = LEMA$
$t = year$ for years 2009-2013

Let the dummy variable (D_{lt}) indicate points of diversion inside the LEMA boundary after the LEMA restrictions were implemented (i.e., 2013). We incorporate the effect of the policy into the empirical model as follows:

$$Y_{ilt} = \alpha_l + \delta_t + \beta D_{lt} + \varepsilon_{ilt}.$$

The treatment effect of being subject to the LEMA is the parameter β defined as follows:

$$\beta = E[Y_{1ilt} - Y_{0ilt}].$$

We can represent the D-I-D using the 2 time periods of data, that is before and after the LEMA as the conditional expectation function. We represent the difference for the LEMA group pre and post treatment as:

$$E(Y_{1ilt} | l = LEMA, t = post) - E(Y_{1ist} | l = LEMA, t = pre) = \delta_{post} - \delta_{pre} + \beta.$$

Similarly, we can represent the difference for the control group, those irrigators located just five miles outside the LEMA boundary as the following conditional expectation function:

$$E(Y_{0ilt} | l = 5mile, t = post) - E(Y_{0ist} | l = 5mile, t = pre) = \delta_{post} - \delta_{pre}.$$

The aggregate causal effect of interest (β) can be obtained by taking the difference in the differences as follows:

$$\begin{aligned} &\{E(Y_{1li} \mid l = LEMA, t = post) - E(Y_{1li} \mid l = LEMA, t = pre)\} \\ - \ &\{E(Y_{0li} \mid l = 5mile, t = post) - E(Y_{0li} \mid l = 5mile, t = pre)\} = \beta. \end{aligned}$$

In the results section below, we show D-I-D results for the key outcomes of interest using aggregate (average) data across the points of diversion. We consider these aggregate results as useful descriptive results, but also estimate regressions as defined next.

Econometric Model

We obtain estimates of the total extensive margin elasticity (β_a) and the total intensive margin elasticity (β_w) directly from the following log-form regressions for the effects on irrigated acres $\ln(a_{it})$ and intensity of applied water per acre $\ln(w_{it})$:

$$\ln(a_{it}) = \alpha_i + \delta_t + \beta_a D_{it} + \varepsilon_{it}^a$$
$$\ln(w_{it}) = \alpha_i + \delta_t + \beta_w D_{it} + \varepsilon_{it}^a$$

where α_i is a point of diversion fixed effect and δ_t is a year fixed effect. We do not include soil or hydrologic variables in our regression because we control for point of diversion fixed effects. We also control for year effects, which account for unobserved heterogeneity that is constant across space for a given year. We do not include weather variables in our regression because we control for year fixed effects and the total area we consider is smaller than a county.

The total effect on water use in response to the policy, in elasticity form, is simply the sum of the extensive and intensive margins.

$$\hat{\beta}_a + \hat{\beta}_w = \hat{\beta}$$

We characterize the intensive margin as having both a direct and indirect effect. We estimate the direct intensive margin by holding land use constant in our regression. Denote $\boldsymbol{S}_{it}$ as a vector of variables indicating the share of irrigated acreage for each land use where land use includes the combination of crop and irrigation technology. The direct intensive margin elasticity is estimated from the following regression:

$$\ln(w_{it}) = \alpha_i + \gamma_t + \beta_{ww} D_{it} + \boldsymbol{\delta S}_{it} + \varepsilon_{it}^a.$$

Hendricks and Peterson (2012) show that we can recover the indirect intensive margin as simply the difference between the total intensive margin and the indirect intensive margin.

$$\hat{\beta}_w - \hat{\beta}_{ww} = \hat{\beta}_{ws}$$

Results

Table 1 lists summary statistics for our sample. The group identified for this study contains 2479 total observations of which we find most irrigators using a center pivot with low drop nozzles (0.86) followed by a traditional pivot (0.08) or pivot and flood combination system (0.04). Additionally we can see in this table that most irrigated acreage is dedicated to corn (0.65), with additional land use equally spread between sorghum (0.17) and soybeans (0.17) and a small amount dedicated to alfalfa (0.02) and wheat (0.04).

Table 1: Summary Statistics of Sample

Variable	Mean	Std. Dev
Irrigation System		
Flood	0.01	0.722
Drip	0.01	0.080
Traditional Pivot	0.08	0.271
Pivot with low drop	0.86	0.350
Sprinkler	0.01	0.096
Pivot & Flood	0.04	0.190
Drip Other	< 0.01	0.053
All Other Irr	< 0.01	0.049
Cropping Type		
Alfalfa	0.02	0.112
Corn	0.65	0.402
Sorghum	0.17	0.113
Soybean	0.17	0.149
Wheat	0.04	0.264
Other Crops	0.19	0.136
Multiple Unknown	0.08	0.264

There is a significant portion of irrigated acreage going to the category identified as other crops (0.19) containing a very diverse group of uses including orchards, golf courses and nurseries and multi-crop (0.08) where the exact combination of crop types is unknown.

Using the D-I-D framework we can estimate the before and after difference inside the LEMA and compare to the before and after difference in the 5 mile buffer zone outside the LEMA. Table 2 shows the D-I-D results for log acres irrigated and log of water use intensity. Irrigators in the 5 mile buffer zone increased irrigated acreage only slightly while irrigators in the LEMA boundary decreased irrigated acres. Overall, we find that the LEMA results in a 3.5% decrease in irrigated acreage. Additionally, irrigators under the LEMA water restriction applied less water accounting for a 34.9% reduction in inches per acre where comparatively irrigators located in the 5 mile boundary had a slight increase in applied intensity.

Table 2: Difference-in-Difference Results for Irrigated Acres and Water Intensity

Log Irrigated Acres	***5Mile***	***LEMA***	***Diff***
Before Policy	4.772	4.869	0.097
	(0.016)	(0.009)	
After Policy	4.782	4.844	0.062
	(0.036)	(0.020)	
Diff	*0.010*	*-0.025*	***-0.035***
Log Water Intensity			
Before Policy	2.447	2.545	0.098
	(0.014)	(0.014)	
After Policy	2.513	2.262	-0.251
	(0.022)	(0.036)	
Diff	*0.066*	*-0.283*	***-0.349***

Notes: Parentheses denote standard errors.

Table 3 indicates how irrigators under the LEMA responded in quantity of irrigated acreage for each crop planted compared to irrigators located within the 5 mile boundary. Although there was some expansion in irrigated acres for alfalfa, sorghum and wheat there were insufficient observations to identify pre/post policy trends for these crops. We do find that irrigators located inside the LEMA had new acreage planted to sorghum where pre policy, there were never irrigated acres of sorghum. We also find, however, that irrigators located in the 5 mile boundary increased acreage planted to sorghum as well.

Irrigators located in the 5 mile boundary expanded irrigated acres of corn whereas irrigators located inside the boundary of the LEMA actually reduced acres such that we find overall irrigators under the water use restriction reduced acreage to corn by 11%. We additionally find that irrigators in both groups were similar in changes of irrigated acreage of soybeans with a slight overall reduction in total irrigated acreage of 3% in response to the water restriction. This seems intuitive and consistent with the high water intensities of these crops.

We also estimate the response of applied water intensity of irrigators located within the LEMA (Table 4). Irrigators located inside the LEMA responded by reducing their average applied water intensity on corn and soybeans compared to irrigators located within the 5 mile boundary who increased their water use intensity and applied more inches per acre to these crops. We find that in total the LEMA reduced applied intensity by 23% for corn and 18% for soybeans. We also find that although we cannot identify a before and after trend for applied intensity to sorghum because irrigators in the LEMA did not have sorghum pre-policy, we do find sorghum irrigators located in the 5 mile boundary increased their applied inches of water per acre whereas irrigators who were under the water use restriction applied less water on average per acre.

Using the results from Table 2, 3, and 4 we see that irrigators moved from high water intensity crops to crops with less water demand and overall irrigated acres were less for irrigators within the LEMA. This indicates that irrigators adjusted by modifying acreage planted to less water intensive crops. Additionally irrigators chose to apply significantly less water intensity on corn and soybeans, the major crops grown in the region.

Table 3: Log of Average Irrigated Acres per Crop Type pre/post LEMA

Crop Type	***5 Mile***	***LEMA***	***Diff***
Corn			
Before Policy	4.77	4.85	0.09
After Policy	4.81	4.78	-0.03
Diff	*0.04*	*-0.07*	***-0.11***
	(0.018)	(0.013)	
	(0.032)	(0.026)	
Sorghum			
Before Policy	3.84	N/A	
After Policy	4.32	4.77	0.45
Diff	*0.48*	*N/A*	
	(0.282)	N/A	
	(0.507)	(0.070)	
Soybean			
Before Policy	4.77	4.78	0.01
After Policy	4.73	4.71	-0.02
Diff	*-0.04*	*-0.07*	***-0.03***
	(0.036)	(0.014)	
	(0.048)	(0.055)	

Notes: Parentheses denote standard errors. N/A denotes there were 0 observations.

Table 4: Average Applied Intensities per Crop Type pre/post LEMA

Crop Type	*5 Mile*	*LEMA*	*Diff*
Corn			
Before Policy	2.55	2.57	0.01
After Policy	2.65	2.43	-0.21
Diff	*0.09*	*-0.13*	***-0.23***
	(0.017)	(0.017)	
	(0.030)	(0.032)	
Sorghum			
Before Policy	1.85	N/A	
After Policy	2.29	1.97	-0.32
Diff	*0.44*	*N/A*	
	(0.283)	N/A	
	(0.251)	(0.070)	
Soybean			
Before Policy	2.41	2.51	0.10
After Policy	2.46	2.39	-0.08
Diff	*0.05*	*-0.13*	***-0.18***
	(0.049)	(0.042)	
	(0.110)	(0.055)	

Notes: Parentheses denote standard errors. N/A denotes there were 0 observations.

Table 5 reports results from our fixed effects regression specification. The extensive and intensive margin elasticity estimates from the log-form fixed effects regressions are reported in columns (1) and (2). We find that the elasticities are significant at the 1% confidence interval which implies the LEMA resulted in a reduction in water use through both the number of acres irrigated as well as the quantity of applied inches per acre. In columns (3) and (4) we condition our estimates to include effects from irrigation system technologies and cropping type in order to estimate the direct intensive margin (i.e., holding constant land use). We find our elasticity measures due to the effect of the LEMA to be only slightly smaller and still significant at the 1% confidence interval.

We find positive coefficient estimates for alfalfa (0.02), corn (0.16) and soybeans (0.05) when compared to crops within the “other” or “multiple crop” category indicating that alfalfa, corn and soybeans are more water intensive crops. The largest water use intensity is attributed to corn which is significant at the 1% level (Table 5). We also see expected signs on the less water intensive crops, sorghum (-0.15) and wheat (-0.16), where we find wheat to be slightly greater and significant at the 5% level.

Table 5: Fixed Effects Regression Estimates

Variable/Statistics	Log Acres (1)	Log Water Intensity (2)	(3)	(4)
LEMA policy effect	-0.05**	-0.37**	-0.35**	-0.35**
	(0.017)	(0.036)	(0.341)	(0.342)
Irrigation System				
Flood				0.21
				(0.191)
Pivot				0.41*
				(0.168)
Drop Pivot				0.36*
				(0.162)
Sprinkler				-0.14
				(0.193)
Pivot & Flood				0.31
				(0.172)
Other Drip				0.17
				(0.165)
All Other Irrigation				0.10
				(0.174)
Cropping Type				
Alfalfa			0.02	0.01
			(0.120)	(0.119)
Corn			0.16**	0.15**
			(0.048)	(0.046)
Sorghum			-0.15	-0.14
			(0.089)	(0.089)
Soybean			0.06	0.06
			(0.050)	(0.049)
Wheat			-0.16	-0.16*
			(0.083)	(0.082)
N	2479	2477	2477	2477
R^2	0.01	0.35	0.38	0.38

Notes: The dependent variable is given by the column heading. Parentheses denote std. errors. ∗ and ∗∗ denote significance at the 5% and 1% levels. The fixed effects regressions control for field-irrigator and annual fixed effects; however we do not report the annual fixed effects here.

We obtain our decomposed elasticity estimates in Table 6 from the regression estimates of Table 5. We find that irrigators reduced total water use on average by 41% in response to the LEMA restriction. Our estimates also show that the largest response occurs at the intensive margin. Our results indicate that irrigators responded primarily by reducing the applied inches of water per acre by 37% while only decreasing irrigated acreage by 5%.

We can additionally obtain the indirect intensive marginal effect (i.e., the effect from changes in cropping patterns) by subtracting the coefficient of direct intensive margin (column 4 of table 5) from the total intensive margin (column 2 of table 5). The estimate of the direct intensive margin response (-0.35) is much larger than the indirect margin response (-0.02) such that the greater influence occurs on intensity reductions to the same crop. Our estimates imply that little change in water use occurs due to changes to cropping patterns or adjustments in irrigation systems.

Table 6: Decomposed Elasticity Estimates of Water Use

Effects	**Elasticity**
Extensive Margin	-0.05
	(0.017)
Intensive Margin	-0.37
	(0.036)
Direct	-0.35
	(0.034)
Indirect	-0.02
Total Marginal	-0.41
	(.0350)

Notes: Parentheses denote standard errors. Estimates of extensive and intensive margins may not sum to total margin due to rounding of estimates.

Conclusion

Our research uses an econometric approach to uncover the effects on water use, crop type, and irrigation technology from the collective action water management plan identified as the Sheridan 6 LEMA. Many agricultural businesses will be directly impacted by changes in these on-farm decisions as well as trickle down impacts on other inputs within the agricultural sector including changes to nutrient purchases and grain flows. The possibility of new water restricted areas has increasingly become a topic for producers and cooperatives and collective action management plans are a potential policy instrument to sustain the life of the High Plains Aquifer for generations to come.

Using a Difference-in-Differences model and fixed effects regression we can expose the causal effect from the LEMA in Kansas and in turn begin to identify the subsequent effects on other input decisions. We are also able to decompose the elasticity estimates to determine effects at the extensive and intensive margins. We find the greatest response to the LEMA at the intensive margin, implying that irrigators chose to reduce their applied water intensity with limited reductions in irrigated acreage.

Additionally we find the greatest intensive margin effect to be identified at the direct intensive margin indicating that the greater proportion of changes to applied inches of water per acre was not due to changes in cropping patterns and irrigation technology but to reductions in applied water use intensities for the same crop type.

We do also find that, consistent with previous literature, irrigators located inside the boundary of the LEMA made relatively small changes to total number of reduced irrigated acres. We also find that some irrigators moved from high water intensity crops to less water intensive crop types. These irrigators additionally chose to apply significantly less water in inches per acre on corn and soybeans when compared to irrigators located in the control group which are the major crops grown in the region. The reduction in water intensity could result in subsequent impacts on applied nutrients to these crops as well.

In general, we find that the collective action management plan was able to reduce water use overall having a positive impact on the aquifer. Irrigators were able to reduce their water use intensity by a larger margin than reductions in irrigated acreage to comply with the provisions they set for themselves. However, we are unable with our data to determine if the reduction in water intensity resulted in reduced crop yields. Future research will add to the data to continue to monitor the progress of the LEMA to uncover any potential adaptations that irrigators exhibit when subject to a water quantity restriction.

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