Policy Leakage or Policy Benefit? Spatial Spillovers from Conservation Policies in Common Property Resources

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Abstract

Common property resources provide important inputs to production but imperfect property rights can lead to their over-exploitation. Often, incentive policies are offered to resource users to address this market failure by allowing users to voluntarily alter behavior. Spillovers from these policies, which may change the decisions of neighboring users, have important implications for their cost-effectiveness. Here, we study whether permanent retirement of groundwater rights in a common property aquifer system impacts groundwater use among active neighboring groundwater users. We find that enrollment in the retirement program causes neighboring wells to pump less groundwater on average due to less competition. However, water use reductions become smaller over time due to the greater resource availability. The results imply that policies that retire water rights may conserve more water than anticipated in the short run, but that over time spillover effects could lead to policy leakage. We also find some evidence that the decrease in groundwater use is not due to non-pecuniary behavioral motivations. Our results shed new light on the importance of spatial spillovers for common property resource management.

1 Introduction

Over-exploitation of natural resources in common property systems has received significant attention within the economics literature. Lack of well-defined property rights, in theory, creates incentives for users competing for the resource to increase their extraction rates above socially efficient levels (Walker, Gardner, and Ostrom 1990; Libecap 2011; Dales 1968). The negative external costs of extracting the resource on other producers creates a need for policy to reduce extraction rates. The cost-effective approach for addressing this market failure involves using incentive-based policies such as taxes on externalities. In practice, such policies are often not feasible and policymakers have approached this problem through the use of second-best policies such as taxes on the use of the resource (S. M. Smith et al. 2017) or subsidizing the adoption of efficient technologies(Hendricks and Peterson 2012; Pfeiffer and Lin 2014).

The cost-effectiveness of these policies depends on the magnitude and the direction of the spillovers caused by the policy (Wu 2000; Alix-Garcia, Shapiro, and Sims 2012).[1] Spillovers in this context are defined as the off-site effects of enrollment on resource use among non-participants. Increased resource use among non-participants can decrease the gains from the policy. While the conservation literature has mostly considered the negative effects of spillovers on the cost-effectiveness of policies, in general, conservation spillovers can be positive or negative and they can increase or decrease the policy gains . This is especially true in the conservation of common property resources where counteracting spillovers lead to theoretically ambiguous effects. On the one hand, conservation increases resource availability for non-participants. This can increase resource use. On the other hand, conservation reduces competition and leads to further conservation among non-participants. Understanding the direction and magnitude of spillovers from conservation is, therefore, critical for studying policy effectiveness.

[1] These effects are sometimes called leakage or slippage effects.

In this paper, we study the spillovers of a voluntary conservation program that provides financial incentives to retire groundwater rights. We first develop a theoretical framework that provides hypotheses regarding the direction of the spillovers. We show that the effect of well retirement on groundwater use at nearby locations is ambiguous. Decreased extraction from the aquifer due to the retired water rights serves to increases future groundwater levels and therefore increases the marginal benefit of using groundwater at nearby locations. Conversely, every unit of water that is conserved by active users is lost to fewer producers in the future, which serves to increase the marginal opportunity cost of using groundwater. To resolve this theoretical ambiguity, we empirically test these hypotheses for the case of the Conservation Reserve Enhancement Program (CREP) in the Upper Arkansas River Basin (UARB) of Kansas. The area is predominantly agricultural and uses groundwater as the main source of irrigation. The stated objective of the program is to reduce groundwater extraction by providing financial incentives to agricultural producers that permanently retire their groundwater extraction rights, which involves shutting off irrigation wells that are tied to the groundwater rights. Groundwater is a shared resource and the spatial nature of groundwater extraction externalities is well documented within the economics literature (Brozović, Sunding, and Zilberman 2010; Pfeiffer and Lin 2012). As a result, while the policy prevents groundwater pumping at the retired wells, the responses of active nearby wells determine the total impact of the program. We study whether the retirement policy results in more resource use or conservation among non-participating producers.

The analysis uses well-level annual groundwater extraction pumping data to econometrically identify the spatial spillovers associated with the CREP program. Using a panel fixed effects approach, we estimate the impact of CREP enrollment on pumping at wells that remain active. Models that include well fixed effects and time controls allow us to explore the effects of the number of neighboring wells retired and the mechanisms driving the spatial spillovers. The spatial and temporal dynamics of the resource play an important role in determining the impact of conservation spillovers.

We find that spillovers from the program complement program goals such that enrollment of a groundwater well in the program results in an average annual reduction of more than 9 acre-feet of water (approximately 5%) for wells that lie within a 2-mile radius of the retired well. Furthermore, we find that an additional retired well results in a 1.7 acre-foot reduction in groundwater use among nearby wells. Exploring the mechanisms through which retirement affects the irrigation decisions of active producers, we find that the common property nature of the aquifer is the main driver of behavior and that non-pecuniary behavioral responses are unlikely to play a significant role.

The research contributes to the empirical literature on the determinants of resource use in common property systems (Grafton, Squires, and Fox 2000; Pfeiffer and Lin 2012; Abbott and Wilen 2011; J. A. Robalino and Pfaff 2012; M. D. Smith 2002) by highlighting the importance of resource competition and stock dynamics on resource use behavior. A main objective of understanding behavior in common property systems is to better achieve resource conservation goals. There is a growing body of literature on optimal resource management over space and time (M. D. Smith, Sanchirico, and Wilen 2009; Xabadia, Goetz, and Zilberman 2006). This literature highlights the importance of considering the spatial nature of resource dynamics for studying resource management policies (Sanchirico and Wilen 1999). We consider the spatial nature of groundwater flow and dissentangle the mechanisms through which resource conservation affects users of a common property resource.

The groundwater retirement policy that we analyze is similar to vessel buyback programs used in fisheries conservation. Previous theoretical and empirical analyses of vessel buyback programs point to the important role of the capitalization and effort decisions of vessels that remain in the fishery for determining the impacts of the policy over time on ecological and economic outcomes (Clark, Munro, and Sumaila 2005; Weninger and McConnell 2000; D. Holland, Gudmundsson, and Gates 1999; D. S. Holland, Steiner, and Warlick 2017). The policy is also similar to that of spatial reserves in fisheries and habitat conservation

(M. D. Smith and Wilen 2003; D. S. Holland and Brazee 1996). We study whether a well retirement policy results in further conservation or resource use at wells that remain in operation. Whereas in the fisheries context both the resource and the user are spatially mobile, in the groundwater context that we study, the resource is mobile but the users are stationary. There is also no potential for additional market entry and existing users have little capacity to expand resource use through capital investments such as well deepening.

We also contribute to the relatively large body of literature on conservation spillovers (Wu 2000; Andam et al. 2008; Lichtenberg and Smith-Ramirez 2011; Alix-Garcia, Shapiro, and Sims 2012; Pfaff and Robalino 2017) in multiple ways. First, the direction and magnitude of spillovers of conservation policies are essentially empirical questions. The existing literature has either relied on aggregate data (Wu 2000) or cross-sectional observations (Alix-Garcia, Shapiro, and Sims 2012). Issues with available data raise concerns regarding unobservable factors that can be correlated with individual resource use decisions. Our use of panel data allows us to identify the spillovers of the conservation policy. Second, Pfaff and Robalino (2017) mention five different channels of conservation spillovers and encourage future research to identify the effect of these channels. Identifying the specific channels is particularly important because they can have opposing effects on resource use or environmental externalities. We find that ecological (physical) spillovers, rather than behavioral non-pecuniary incentives, are the main driver of the conservation decisions. Third, the literature that studies spillovers from conservation policies has primarily focused on forest and land conservation. Little empirical evidence exists on the spillovers of conserving shared resources such as groundwater stocks. Studying groundwater conservation provides us with an opportunity to expand the existing knowledge to a case where enrollment in the retirement program can result in potential positive or negative effects on resource use by nearby producers through physical resource links and the common property nature of the resource.

Finally, following Gisser and Sanchez (1980), a large body of literature has considered the potential benefits of aquifer management using analytical and numerical models. Such studies rely on assumptions of optimal groundwater extraction, which may not reflect real policy targets and are an upper bound on policy effectiveness (Fenichel and Hashida 2019). Recent empirical studies evaluate the effects of aquifer management on land values (Edwards 2016) and on irrigation decisions of producers (Drysdale and Hendricks 2018; S. M. Smith et al. 2017; S. M. Smith 2018). We contribute to this literature by studying the effects of a groundwater right retirement policy. Groundwater aquifers are being depleted rapidly in many parts of the world. Understanding the effectiveness of existing groundwater management policies can provide further insight into the design of future policies.

The paper is organized as follows. In Section 2, we provide a theoretical model of groundwater extraction when neighboring wells enroll in conservation. Section 3 explains the study region and the design of the policy. Section 4 discusses the data. Section 5 provides the identification strategy. Section 6 shows our results, including support for the hypotheses, mechanisms and robustness checks. The paper concludes in Section 7.

2 Theoretical Model

In this section, we present a two-period model of common property resource use to investigate how the retirement of resource extraction rights impacts the behavioral incentives faced by active CPR users. We assume that groundwater users are forward looking and consider the dynamic implications of their groundwater use decisions. We first use the model to examine the impact of the number of competitors in a CPR on the use of the resource, conditional on the available stock. Then, because well retirement leads to higher stocks over time, we examine the impact of those higher stocks.

Groundwater, ω is an input to production with profit $\pi(.)$ in each time period. $\pi(.)$ is increasing and concave in water use, i.e., $\pi'(\omega) > 0$ and $\pi''(\omega) < 0$. Producer i maximizes the present value of the profit:

$$
\begin{aligned}
\underset{\omega_1,\omega_2}{\text{Max}} \quad & \pi(\omega_1) + \delta\pi(\omega_2) \\
\text{subject to} \quad & \omega_1 + \omega_2 = X_1\Big(1 - f(\omega_1, N)\Big)
\end{aligned}
\tag{1}
$$

where δ is the discount factor, ω_1 and ω_2 are groundwater use of well i in periods 1 and 2 respectively. X_1 is the stock level for well i at period 1. Finally, $f(\omega_1, N)$ is the share of groundwater stock that is lost to the N producers who share the stock of groundwater from the first period to the second period. The properties of the f function include $f(X_1, N) = 0$, i.e., if all the resource is used in period 1, then there is nothing left to lose to other producers and the producer is able to use the entire available stock, X_1, in the first period. Furthermore, $f_1(.) < 0$ so that as the amount of water extracted in the first period increases, a smaller share of the unextracted water is lost to other producers between periods 1 and 2. Also, $f_2(.) \leq 0$ such that as the number of producers who share the resource increases, less of the resource stock that is not used in period 1 is available for the second period for well i. Moreover $f_{12} < 0$. This condition suggests that with greater N, the share of conserved water available for period 2 increases faster as ω_1 increases. This condition also implies that when no water is used in period 1, more water is lost to the competitors. On the other hand, when all the water is used in period 1, i.e., $\omega_1 = X_1$, there is no difference in the amount of water that is lost to the competition. Figure 1 shows agraphical representation of this fucntion. Finally, we assume that the stock is exhausted at the end of the second period. In other words, the groundwater stock is scarce. The profit maximization problem can be written as:

$$
\pi(\omega_1) + \delta\pi\Big(X_1(1 - f(\omega_1, N)) - \omega_1\Big) \tag{2}
$$

The first order condition (FOC) for an interior solution is:

$$
\pi'(\omega_1) = \delta\pi'(\omega_2)\Big\{1 + X_1 f_1(\omega_1, N)\Big\} \tag{3}
$$

The marginal profit of pumping groundwater in the first period is equal to the marginal opportunity cost of using water in period 1. From the FOC, since the left hand side is positive, we know that $\Big\{1 + X_1 f_1(\omega_1, N)\Big\} \geq 0$. The intuition is that for every unit of groundwater pumped in period 1, less than one unit is available in the second period as some of it is lost to the other users who share the resource. Pumping more groundwater in period 1 will decrease the amount that is lost to other producers. Furthermore, $\Big\{1 + X_1 f_1(\omega_1, N)\Big\} \leq 1$ because for $\Big\{1 + X_1 f_1(\omega_1, N)\Big\} > 1$, $X_1 f_1(\omega_1, N)\Big\}$ needs to be greater than 0 which is not the case in our model.

We can write Equation 3 as $G(\omega_1, X_1, N)$:

$$G(\omega_1, X_1, N) = \pi'(\omega_1) - \delta\pi'\Bigg(X_1(1 - f(\omega_1, N)) - \omega_1\Bigg)\Bigg(1 + X_1 f_1(\omega_1, N)\Bigg) \tag{4}$$

Taking the total derivative of $G(.)$ with respect to ω_1 and N, we get:

$$\frac{\partial \omega_1}{\partial N} = -\frac{G_N}{G_{\omega_1}} = -\frac{\delta\pi''(.)(-X_1 f_2(.))(1 + X_1 f_1(.)) - \delta\pi' X_1 f_{12}(.)}{< 0} \tag{5}$$

The denominator of Equation 5, G_{ω_1}, is negative because it is the second derivative of the concave profit with respect to ω_1. Therefore the sign of $\frac{\partial \omega_1}{\partial N}$ depends on the sign of the numerator.

The impact of higher N on pumping in the first period has two counteracting effects. First, more N decreases the amount of water available in the second period (a stock effect). This raises the marginal cost of water used in the first period, leading to reduced pumping with more N. Second, higher N means that less of the water conserved in the first period remains available for use in the second period (a water loss effect). This decreases the marginal cost of water use in the first period and leads to more pumping. As N decreases, the first effect increases pumping while the second effect decreases it. Taken together, the net effect of one fewer well on the groundwater use of well i is ambiguous. When the stock effect dominates, groundwater use increases as a result of fewer wells extracting groundwater. However, if the water loss effect dominates, then groundwater use decreases as a result of fewer wells. Which effect dominates is an empirical question.

Furthermore, as initial stock at well i increases, we have:

$$\frac{\partial \omega_1}{\partial X_1} = -\frac{G_{X_1}}{G_{\omega_1}} = -\frac{\delta\pi''(.)f(.)(X_1 f_1(.) - 1) + \delta\pi'(.)f_1(.)}{< 0} > 0. \tag{6}$$

As saturated thickness in period 1 increases, pumping at period 1 increases.

To summarize the net impacts of well retirement on pumping at an active well, Figure 2 provides an illustration assuming that the competition effect is negative, i.e., $\frac{\partial \omega_1}{\partial N} < 0$. In the initial period, the producer determines the profit maximizing amount of groundwater use, ω_1, by setting marginal profit of water use equal to MOC. In the subsequent period when some wells retire such that $N_1 < N_0$, the marginal opportunity cost of extracting groundwater today increases and the dynamic and profit maximizing producer reduce the amount of groundwater used. However, retirement of the well also results in an increase in groundwater levels which increases groundwater use. If the number of wells remains at N_1, increasing groundwater levels over time increases groundwater use.

In conclusion, we hypothesize that the effect of an increase in the number of retired groundwater wells on groundwater use is ambiguous. If retiring groundwater wells increase groundwater levels over time compared to the counter-factual, we expect that water use will increase over time relative to the initial reduction.

3 Conservation Reserve Enhancement Program in the Upper Arkansas River Basin

Southwestern Kansas is a predominantly agricultural area and groundwater from the High Plains Aquifer is a major source of water input for irrigated agriculture in the region. High demands from irrigated agriculture and the common property nature of the aquifer have led to sub-optimal declines in aquifer levels over the past several decades (Scanlon, 2012). The Upper Arkansas River Basin (UARB) CREP intends to reduce aquifer depletion and also restore the health of the Arkansas River through incentive-based groundwater conservation. The UARB CREP is a part of the Conservation Reserve Program (CRP) and covers the area along the Arkansas River in Southwest Kansas consisting of 10 counties (Fig 3).

The program provides financial incentives to individual farmers to permanently retire their water rights by enrolling irrigated acres. The enrolled acres are put to approved land uses such as native grass. It is worth noting that while the program enrolls irrigated acres, the volume of annual authorized water right allocations are retired so that one cannot reallocate groundwater from the enrolled acres to non-enrolled acres. Given that land use switches from irrigated agriculture to native species and irrigation rights are retired, neighboring producers are aware of the enrollment of a parcel in CREP.

The enrollee receives annual payments for up to 15 years. According to the Kansas Department of Agriculture, the annual rental rates as of 2016 were between $153 and $193 per acre. The variation in rental rates is due to the location of the parcels in the Hydrologic Unit Code (HUC) and the irrigation technology. For producers to be eligible to enroll their acres in CREP, they need to use at least 50% of their water rights in three out of the last five years and apply at least half an acre foot of groundwater per acre in four out of the six years prior to their enrollment. Finally, at least 51% of the enrolled land needs to be within the boundary of the UARB CREP.

Currently, Kansas law restricts enrollment so that no more than 25% of total enrolled CREP acres can be allocated to one county. As a result, the program allocated a cap of 5,000 acres per county in 2008. The cap was then raised to around 7,200 acres per county in 2011. In 2017 this cap was further raised to 10,000 acres per county and to 28,950 acres for the entire CREP area.

4 Data

We use two primary sources of data in this study. The Water Information Management and Analysis System (WIMAS) dataset from Kansas University and Kansas Geological Survey provides spatial well-level data including seasonal groundwater use, irrigated acres and an identifier for the individual producer that uses the groundwater for irrigation. The period of WIMAS data that we use in this study is between 2001 and 2016. The second source of data that we use is the UARB CREP water rights enrollment information. This dataset provides information on specific groundwater rights that were retired by year since the start of the program in 2008. It also provides us with the boundaries of the UARB CREP area. The data were obtained from the Kansas Department of Agriculture through the Freedom of Information Act. There were 170 wells enrolled in the UARB CREP between 2008 and 2017. Producers are often given up to 2 years to fully retire their water use after enrollment. Figure 4 shows the number of wells retired over time. Many of the producers that enrolled their in the program in 2008, retired their water rights in 2010.

We combine these two sources of data and to define which wells are affected by neighbor enrollment in CREP,we consider wells within different radii of a well that enrolls in CREP. Since few of the CREP wells are on the border of the CREP area, we consider all the wells in the CREP region and also include wells within a 5-mi buffer within which pumping wells could be affected by CREP retirement.

Other sources of data that we use in this study include spatially-explicit measures of growing season precipitation and growing degree days from the PRISM dataset from Oregon State University, hydraulic conductivity from U.S Geological Survey (Cederstrand and Becker 1998), and saturated thickness from Haacker, Kendall, and Hyndman (2016). The climate data allow us to determine average monthly well-specific precipitation and growing degree days. Hydraulic conductivity is a measure of the speed of lateral flow of groundwater in a specific part of the aquifer and is a proxy for how shared an aquifer is. The greater the hydraulic conductivity, the more shared (common) the aquifer is in that area. Saturated thickness is a measure of the depth of the aquifer, and thus groundwater availability, at a given location above the aquifer. Annual well-level saturated thickness data allow us to explore the role of resource availability on the irrigation decisions of producers.[2]

Figure 5 shows average groundwater extraction for wells within a 2-mile buffer of the CREP wells, wells between 2 and 4 miles from the CREP wells, and wells greater than 4 miles from the CREP wells. It shows that after the start of the CREP program in 2008, groundwater use for wells within a 2-mile radius of CREP wells decreased relative to the wells in the 2- and 4-mile radii of the CREP wells. The figure provides suggestive evidence that CREP may have resulted in conservation among active neighboring wells and that the effect may be due to spatial nature of groundwater flow.

Table 1 further shows the summary statistics for CREP wells, wells within a 2-mile radius of CREP wells and wells outside a 2-mile radius of the CREP wells before the start of the program, i.e., before 2008. The table shows that the wells within a 2-mile radius on average used less groundwater than the CREP wells but on average used more groundwater than the wells outside the 2-mile radius of the CREP wells. Furthermore, CREP wells and wells within a 2-mile radis of CREP wells have higher saturated thicknesses than the rest of wells in the region. These statistics suggest that the program has been successful in retiring wells that iimpose a greater externality in terms of stock depletion in areas with rapid depletion

[2]For some observations there are multiple wells that operate as a unit. For these wells, annual water use is reported for the geometrical center of the wells, which is not the location of an actual well. For these observations we only consider the geometrical center.

rates. The aquifer characteristics are similar across the region, but wells outside a 2-mile radius of CREP wells get more precipitation and have higher growing degree days. Irrigated acres are similar across the wells suggesting that most wells irrigated quarter section center pivot circles that are around 130 acres.[3] Finally, there are on average about 2.87 wells that enroll in CREP within the 2-mile radius of the treated wells.

5 Empirical Strategy

To test the hypotheses provided in Section 2 regarding the direction and timing of the spillovers from groundwater conservation, we study the effect of enrollment of groundwater wells in CREP on irrigation decisions at active neighboring wells. Our main specification is a panel fixed effects model. Under this specification we study the effects of CREP enrollment for an average well that experiences one or more of their neighboring wells enrolling in CREP. The average effects are estimated with:

$$Y_{ict} = \gamma_1 D_{ict} + \gamma_2 X_{ict} + \mu_i + \eta_{ct} + \epsilon_{ict}, \tag{7}$$

where Y_{ict} is the total amount of groundwater extracted in year t by well i in county c, measured in acre-feet. D_{ict} is an indicator that is equal to 1 when well i is treated, i.e., if well i has any wells enrolled in CREP within a specified radius in year t. X_{ict} is a vector of control variables that includes growing degree days in the growing season, growing season average precipitation and saturated thickness measured prior to the growing season. μ_i is a well fixed effect and η_{ct} is a county by year fixed effect. The coefficient γ_1 provides the average effect of the program on treated neighboring wells.

The sample considered in this specification is all the wells within an R-mile radius of the CREP wells. The identification in Equation 7 comes from variation in the timing of treatment

[3] The size of a PLSS quarter section is about 160 acres. However, corners of the quarter section are often not irrigated.

for different treated wells. All the wells in the sample will be treated at some point during the analysis. Previous analysis (Manning et al., 2019) shows that about 80% of the effects of groundwater well retirements after one year dissipate within 2-miles of the retired well. As a result, we consider a 2-mile radius as the main specification in the rest of the paper. Our identifying assumption is that the decisions of producers to enroll their wells in CREP is exogenous to the irrigation decisions of their neighboring producers. We avoid concerns about endogenous reallocation of groundwater use among CREP enrollees by removing from the sample all the wells operated by individuals that enroll one or more of their wells in the program.

We also study the marginal effects of the number of CREP wells enrolled on groundwater extraction decisions of active neighboring producers. To study the effect of an additional well enrolled in CREP on irrigation decisions at the treated wells, we use the following specification:

$$Y_{ict} = \beta_1 N_{ict} + \beta_2 X_{ict} + \mu_i + \eta_{ct} + \vartheta_{ict}, \tag{8}$$

which is the same as Equation 7, except that N_{ict} is the cumulative number of wells that have enrolled in CREP within a specific radius of well i as of year t. The coefficient β_1 measures the effect of an additional well enrolled in CREP on groundwater use of an active neighboring well.

We estimate both Equation 7 and Equation 8 with and without including saturated thickness as a control variable. If water loss effect due to competition is the dominant force in affecting irrigation decisions, we expect both γ_1 and β_1 to be negative in the models that exclude saturated thickness. If the saturated thickness effect dominates, these coefficients could be positive.

Finally, as shown in Section 2, as producers enroll their wells in CREP, groundwater levels in the vicinity of these wells should see a relative increase over time. Thus, it is important to disentangle the effects of the number of retired wells from the changes in the resource stock. Over time, more wells enroll in the program. This could further increase or decrease water use. On the other hand, due to previous enrollment of wells in the program, active wells may experience an increase in their groundwater levels over time. To capture these effects and the dynamics of changes in groundwater use over time, we consider both a time effect and the effect of the number of wells, i.e., we estimate the specification:

$$Y_{ict} = \nu_1 N_{ict} + \sum_{k=1}^{T} (\nu_2^k + \nu_3^k N_{ict}) \Lambda_{ict}^k + \nu_4 X_{ict} + \mu_i + \eta_{ct} + \xi_{ict}, \tag{9}$$

where Λ_{ict}^k is an indicator that is equal to 1 for year k and equal to zero otherwise. $\nu_2^k + \nu_3^k N_{ict}$ captures the effects of both an increase in the number of wells enrolled and the dynamic changes in aquifer levels over time. We consider eight post-treatment years including the first year of treatment, i.e., $T = 8$. Note that since we are using well fixed effects, these regressions only include wells that eventually have an enrolled well within their 2-mile radius, similar to the two previous models. Also, since we want to focus on the dynamic effects of well retirement over time, we do not include saturated thickness in the regression as a control variable.

6 Empirical Results

6.1 Main Results

The first set of results evaluates groundwater use among active wells that are within a 2-mile radius of wells that enroll in the CREP program (Table 2 columns 1-3). The results show that an average well reduces its annual groundwater use by about 9.6 acre-feet (AF) (~ 5%), when one or more wells within a 2-mile radius enroll in CREP. This result is robust to the inclusion of saturated thickness and the magnitude of the effect does not change significantly.

The fact that the coefficient on the indicator for nearby participation in CREP is negative in the model that excludes the saturated thickness control variable suggests that the water loss effect from competition dominates the saturated thickness effect in the short run. That the coefficient on the CREP participation indicator changes very little when saturated thickness is included in the model suggests that there is a relatively weak correlation between the retirement of wells nearby and changes in saturated thickness in the short run.[4]

The negative coefficient on nearby CREP participation is also robust to the inclusion of a CREP-well by year fixed effects. These fixed effects capture the potential differences in local conditions around each of the wells that enroll in the CREP program that are not captured by other controls or by the county-year fixed effects. While the magnitude of the effect is about 25% greater, it is not significantly different from the other two specifications.

The average effect of CREP enrollment is negative for an active well. The second set of results provides the coefficient estimates for the specification in Equation 8, which includes the number of wells participating in CREP as an independent variable. The results show that an additional well enrolled in CREP results in a decrease in groundwater use among active neighboring producers of about 1.7 AF ($\sim$ 1%) per year (Table 2 columns 4-6). This outcome provides evidence for the hypothesis that reducing competition for a common property resource generates further reductions in extraction rates among active users of the resource. It is well established within the economics literature that competition for the resource and lack of well defined property rights can result in myopic extraction decisions and total extraction rates that exceed the rate when one agent has complete property rights over the resource (Gordon 1954). Here, by showing that reducing resource competition decreases resource extraction, we show that conservation policies can reduce this externality. We also, indirectly, show support for the hypothesis that under a lack of well defined property rights, we expect to see over-extraction from the resource even on a per-extractor basis.

[4]Standard errors are clustered at the well-level which are larger than Conly's spatial HAC standard errors (Conley 1999).

In Section 2 we also hypothesize that participation in CREP could cause nearby groundwater extraction rates could increase as saturated thickness levels increase near the retired wells. More specifically, as aquifer levels recover relative to the no-policy counter-factual, we expect to see initial reductions in groundwater use among active producers dissipate over time. Our results show that these effects dissipate within a relatively short period of 5 years (Figure 6). This figure shows the estimated value of the terms $\nu_2^k + \nu_3^k N_{ict}$ in Equation 9 for the average number of wells enrolled in CREP within a 2-mile radius of an active well (2.87 wells) for years 1 through 8. Together these results show that producers reduce their groundwater use in response to less competition for the common property resource. As aquifer levels recover over time, however, they pump more groundwater, which counteracts the competition effect. In the next subsection, we study the mechanisms through which the policy and the retirement of neighboring wells affect the groundwater use decisions of neighboring producers.

6.2 Mechanisms

6.2.1 Common Property Resource

In Section 6 we show that recovering groundwater levels result in an increase in groundwater extraction over time. Here, we test whether groundwater levels increased as a result of the program. We use the same specification as in Equation 8 except that here, Y_{it} is the saturated thickness of the aquifer at well i in year t and we remove saturated thickness from the RHS. We find that after the program saturated thickness levels recover such that one more well enrolled in the program results in an increase in groundwater levels of about 0.2 ft every year relative to the counter-factual of no policy (Table 3).[5]

The results shown in Figure 6 do not include saturated thickness as an independent variable. If, in Equation 9, instead of groundwater use we use the difference in saturated thickness from year $t-1$ to year t as the dependent variable, we find that over time saturated thickness

[5]Groundwater levels overall are decreasing over time.

level have been recovering as a result of the policy (Figure 7).

To examine if the effect is transmitted through the dynamics of the common property resource, we test if areas with a more shared aquifer generate larger conservation effects from the policy (Table 3). Our hydraulic conductivity variable does not vary significantly over the 2-mile buffer of a CREP well. This could be due to small variability of conductivity over a small spatial scale or due to the binning of the variable. As a result, while in the specification that includes the number of wells interacted with the conductivity variable (Table 3 column 2), the sign of the variable is negative, the standard error is relatively large. As a result, we also include the specification with the post treatment variable interacted with conductivity (Table 3 column 3) which shows that the interaction term is significant at the 5% level. The magnitude of the variable is not small, suggesting that the shared nature of the aquifer may be an important determinant of groundwater use decisions, further confirming the common property resource hypothesis.

6.2.2 Non-Pcuniary Motivations

We may observe conservation among active producers due to behavioral non-pecuniary reasons (Pfaff and Robalino 2017; S. M. Smith 2018). For example, they may be affected by their neighbor's decision to enroll in a conservation program to conserve groundwater. To test this hypothesis, we exploit a unique feature of our dataset. In our data, we observe the location of all the wells owned by an individual. We hypothesize that if there are behavioral reasons for reducing groundwater use in the neighborhood of a CREP well, we should observe similar conservation behavior among the wells that are owned by the treated individuals that are not within a 2-mile radius of any CREP wells. We test this hypothesis by estimating the effect of the average number of wells enrolled in the CREP program for each well outside a 4-mile radius that is owned by an individual that has a well inside the 2-mile radius. Columns 4 and 5 of Table 3 show the results of this exercise for two different distance bands. Wells within the 4 to 10-mile radius and wells within the 10-15 mile radius. As expected, the number of wells owned by the treated individuals decreases with the distance. We find no evidence that CREP enrollment affects groundwater use of wells that are not nearby the CREP wells.

We also find that producers did not decrease their water use in expectation of their neighbors retiring their groundwater wells nor did they increase their groundwater extraction to force out neighboring producers (Figure 8). Figure 8 also provides support for the exogeneity of the decisions of producers to enroll their wells in CREP and the neighbors' groundwater use decisions.

6.2.3 Margins of Adjustment

Finally, it is also important to understand the margins along which producers reduce their groundwater irrigation. It is possible that farmers respond through short term measures such as reducing irrigated acres or by longer term measures like changing farming strategies. We find that while the number of acres irrigated does not change significantly, farmers adjust their water use by changing the mix of crops they irrigate (Table 4). By estimating a linear probability model of a producers' planting decisions, we find that farmers switch to less water intensive crops. This is in line with the literature that find that policies that reduce the race to extract shared resources result in a change towards more sustainable strategies (Reimer, Abbott, and Wilen 2014; Reimer and Haynie 2018).

6.3 Robustness Checks

We consider the robustness of our results in two different ways. First, we consider the sensitivity of our estimates to the distance from the CREP wells. Second, we consider different specifications.

6.3.1 Robustness to Distance Bands

Table 5 shows that our estimate of the average and marginal effects are slightly smaller under a 3-mile radius buffer instead of a 2-mile radius buffer (columns 1 and 4). The slightly smaller point estimates may suggest the dissipation of the effects over space. Furthermore, while we have removed all the wells that are owned by the individuals enrolled in CREP, we find that our average estimates are robust to including these wells in the sample while the marginal effects are smaller in magnitude (columns 2 and 5). Finally, we also consider all wells within a 9-mile radius within which we consider weighting the observations by the inverse square of their distance from their closest CREP well. We find that our results of the marginal effects are robust to this specification (column 6).

6.3.2 Robustness to different specifications

Table 6 further shows the robustness of our estimates. We find that our estimates are robust to including a more flexible form of saturated thickness, i.e., $saturated\ thickness^2$, as the effect of the changes in saturated thickness on water use may not be linear (columns 1 and 4). Furthermore, the unit of observation in our analysis is a well at a specific location (longitude and latitude). We choose this unit of observation because we are interested in the spatial relationship between retired wells and active wells. Other studies, e.g., Drysdale and Hendricks (2018), define the unit of observation based on water right and well id. We find that our estimates are also robust to considering *well id* that is defined by the WIMAS system (columns 2 and 5). Moreover, the marginal effect considered in the analysis is the effect of an additional well retired on the water use of the active neighboring wells. We could also look at the effect of an additional unit of water retired on water use of the active wells. To do so, we consider the maximum amount extracted by the CREP wells before their retirement. We find that an acre-foot retired results in an average reduction in extraction of about 0.004 acre-feet (column 3). The total number of competitors in the neighborhood of a treated well could also affect their groundwater use. To test for the robustness of our results to the baseline competition, we test for the effect of the ratio of CREP wells within a 2-mile radius, which is the ratio of cumulative number of wells retired in year t to the total number of wells irrigating before 2006 before the program started. We show that our result is robust to this specification and as the ratio of wells retired within a 2-mile radius of well i increases, groundwater use at well i decreases (columns 3 and 6).

Finally, we consider a differences in differences specification in which we compare the annual groundwater use of active wells within an R-mile buffer of the CREP wells (treated wells) to groundwater use at wells outside the buffer. Specifically, we estimate:

$$Y_{it} = \alpha_1 Treated_{ic} + \alpha_2 Treated_{ic} \times post_t + \alpha_3 X_{it} + \lambda_t + \eta_S + \mu_P + \epsilon_{it} \tag{10}$$

Where Y_{it} is water use for well i in county c in year t. We condition our estimates on saturated thickness, mean growing season precipitation and growing degree days. We also consider other controls such as longitude, latitude, crop type, irrigation technology, hydraulic conductivity and authorized quantity which is the amount permitted to pump by each well. We also consider year fixed effects, λ_t, section fixed effects, η_S, and CREP well fixed effects, μ_P, which captures any unaccounted for characteristics within an R-mile radius of a CREP well that are not time-varying. The Public Land Survey System (PLSS) divides the area of the United States into squares of 1-mi by 1-mi that are called sections.

We find similar estimates for the effect of the program on average groundwater use of the active neighboring wells further supporting the robustness of our estimates (Table 7). Notice that with section and CREP well fixed effects and year fixed effects treatment status and post treatment are perfectly correlated with the fixed effects. Our results show that the estimates of the average effects of CREP enrollment is robust to the inclusion of different control variables. Our estimates are also robust to considering the 3-mile radius buffer instead of the 2-mile buffer (column 3). Finally, clustering of standard errors at the CREP well levels allows for correlation of the error term across all the wells that are within the 2-mile radius of a CREP well. Under this clustering, it is assumed that the error terms for all the control wells are correlated.

7 Discussion

In this research we study the behavioral response of active agricultural groundwater users to the retirement of nearby wells. Our findings show that on average nearby producers reduce their groundwater use, which suggests the significance of the resource loss effect of the competition within a CPR. The initial reduction in groundwater use following the retirement of nearby wells, however, has only a temporary effect. Over time their extraction rates revert to levels that are not significantly different than they were prior to the nearby wells retiring. Our results have a few implications for understanding the behavior associated with CPR use and for understanding the effectiveness of CPR management policies.

We find support for a competition effect wherein conservation is incentivized when CPR competition is relaxed. This finding provides empirical insight regarding CPR over-extraction, which is important for three reasons. First, while the theoretical models have extensively shown the over-extraction of common property resources, this literature often suggests that higher aggregate extraction but lower individual extraction rates as a result of more competition for the resource. This could be, for example, due to a congestion externality as the number of individuals that extract the resource increases. Here, we find that the resource loss effect which disicentivizes conservation further when competition increases can increase CPR use. Second, while the economics literature primarily focuses on marginal policies such as taxes, retirement policies may provide a more clear signal regarding reduced CPR competition. The "co-benefits" of retirement programs from any additional conservation should be considered when estimating their benefits. Furthermore, if the mechanism through which water rights retirements affect nearby groundwater use is the competition effect, targeting areas with greater competition could potentially generate greater benefits. Policymakers may benefit from providing incentives such as agglomeration bonuses (Parkhurst et al. 2002) that target reduced competition in portions of the CPR that are highly competitive. We note that while we show the competition effect and the incentive to conserve in a specific context, this finding can potentially exist in extraction of other CPRs such as fisheries, forests, and grazing lands. Future research should consider disentangling the competition effect from other sources of inefficiency in other CPR contexts.

While we provide evidence regarding the existence of spatial spillovers, estimating the benefits generated by such spillovers as well as from the policy itself requires an integrated hydro-economic model. The cost-effectiveness of the policy depends on the changes in groundwater levels and extraction as a result of the policy. Given the dynamic nature of groundwater extraction, ignoring the potential spillovers of groundwater conservation can result in under-estimating or over-estimating the effectiveness of the program. When conservation results in a decrease in groundwater use at nearby wells, this will increase groundwater levels relative to the counter-factual over time. The increase in aquifer levels can eventually be expected to increase groundwater use. As such, a groundwater retirement program is unlikely to permanently reduce overall groundwater extraction from an aquifer. It will, however, serve to re-time when groundwater is used, from current periods to future periods. The length of time that aquifer levels are higher under the policy relative to the counter-factual ultimately determines the cost-effectiveness of the program. Future research should utilize a dynamic hydro-economic modeling framework that captures the complex behavioral responses to evaluate the benefits over time associated with specific groundwater conservation programs.

Voluntary conservation programs have become one of the main policy tools for reducing externalities from agricultural production in the United States and across the world (Lichtenberg and Smith-Ramirez 2011; Bennett 2008; Baylis et al. 2008; Alix-Garcia, Shapiro, and Sims 2012). For example, the Conservation Reserve Program (CRP) provides around $1.8 billion annually to agricultural producers in the United States to encourage voluntary conservation. Despite their popularity, however, the cost-effectiveness of these conservation programs has been questioned, in part due to the existence of potential spillovers (Wu 2000; Alix-Garcia, Shapiro, and Sims 2012). We show that, in the case of CPR conservation, spillovers can be complementary to the goals of the policy.

A decrease in groundwater extraction by active users is complementary to the goals of the policy when further entry and rent dissipation is not possible. However, the increase in stock levels, relative to the counterfactual, could potentially result in an increase in resource extraction by active users in the long term through lower pumping costs. The importance of changes in resource use by non-participants over space and time depends on the goals of the policy. If the goal of the policy is to extend the life of the resource by permanently reducing resource extraction, an increases in extraction of the resource by non-participants can undermine the policy's efficacy. On the other hand, if the goal of the policy is to reallocate water use to more productive producers in the future, the success of the policy will critically depend on whether and when individuals increase their use of the resource.

8 Figures and Tables

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Table 1: Summary statistics for CREP wells, wells within a 2-mile radius of CREP wells and wells outside the 2-mile radius of CREP well before 2008.

variable	CREP wells	<2 miles	>2 miles
Groundwater extraction (AF)	206.961	195.930	162.900
Saturated thickness (ft)	159.956	173.890	124.500
Precipitation (mm)	56.030	59.430	68.790
Growing degree days	2,032.724	2,029.390	2,067.500
Hydraulic conductivity (lower bound)	60.727	64.720	62.040
Hydraulic conductivity (upper bound)	121.454	129.430	124.490
Acres irrigated	132.827	141.640	141.970

Table 2: The average (columns 1, 2 and 3) and marginal (columns 4, 5 and 6) effects of the CREP program on water use of the neighboring active wells within 2-mile radius.

	Groundwater Extraction (AF)					
	(1)	(2)	(3)	(4)	(5)	(6)
Post treatment	-9.630^{***}	-9.598^{***}	-12.632^{**}			
	(2.843)	(2.839)	(5.515)			
Number of CREP wells				-1.687^{***}	-1.601^{**}	-2.025
				(0.631)	(0.632)	(1.748)
Growing degree days	-0.087	-0.160^{*}	-0.322	-0.096	-0.171^{*}	-0.322
	(0.092)	(0.093)	(0.320)	(0.092)	(0.093)	(0.321)
Growing season precipitation	-0.706^{***}	-0.744^{***}	-0.547^{*}	-0.729^{***}	-0.768^{***}	-0.579^{*}
	(0.108)	(0.108)	(0.325)	(0.107)	(0.108)	(0.325)
Saturated thickness	0.409^{***}			0.423^{***}		
	(0.150)			(0.152)		
County by year fixed effects?	Yes	Yes	No	Yes	Yes	No
CREP well by year fixed effects?	No	No	Yes	No	No	Yes
Well fixed effects?	Yes	Yes	Yes	Yes	Yes	Yes
Observations	14,042	14,042	14,042	14,042	14,042	14,042
R^2	0.698	0.697	0.756	0.698	0.697	0.756
Adjusted R^2	0.660	0.660	0.683	0.660	0.659	0.683

Note: *p<0.1; **p<0.05; ***p<0.01

Standard errors are clustered at the individual level

Table 3: The effect of the number of wells in CREP on saturated thickness of the neighboring active wells (column 1) and the effect of hydraulic conductivity on groundwater use of the neighboring active wells within 2-mile radius (columns 2 and 3).

	Saturated thickness	Extraction	Extraction	Extraction, 4-10 mi	Extraction, 10-15 mi
	(1)	(2)	(3)	(4)	(5)
Number of CREP wells	0.204**	−0.818		−2.306	4.758
	(0.099)	(0.747)		(1.532)	(3.360)
Post treatment			−4.140		
			(3.644)		
Growing degree days	−0.178***	−0.094	−0.084	0.019	0.109
	(0.010)	(0.091)	(0.091)	(0.197)	(0.136)
Growing season precipitation	−0.093***	−0.730***	−0.717***	−1.133***	0.036
	(0.014)	(0.107)	(0.108)	(0.221)	(0.242)
Saturated thickness		0.412***	0.398***	−0.031	0.310
		(0.151)	(0.150)	(0.225)	(1.067)
Number of CREP wells × high conductivity		−2.100*			
		(1.191)			
Post treatment × high conductivity			−11.488**		
			(4.543)		
County by year fixed effects?	Yes	Yes	Yes	Yes	Yes
Well fixed effects?	Yes	Yes	Yes	Yes	Yes
Observations	14,042	13,913	13,913	4,252	899
R^2	0.995	0.696	0.696	0.748	0.830
Adjusted R^2	0.994	0.659	0.659	0.706	0.787

Note: *p<0.1; **p<0.05; ***p<0.01
Standard errors are clustered at the individual level

Table 4: The effect of the number of wells in CREP on irrigated acres, intensive margin application and probability of growing each crop for the neighboring active wells within 2-mile radius.

			Probability of growing				
	Irrigared acres	Groundwater application	Alfalfa	Corn	Sorghum	Soybean	Wheat
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Number of CREP wells	0.525	−1.845***	−0.016***	−0.012***	0.001	0.001	0.002
	(0.329)	(0.614)	(0.004)	(0.005)	(0.001)	(0.002)	(0.002)
Growing degree days	0.057	−0.115	0.001	−0.001	0.0002	0.0001	0.0003
	(0.037)	(0.091)	(0.0005)	(0.001)	(0.0002)	(0.0002)	(0.0003)
Growing season precipitation	0.060	−0.745***	−0.001	0.001	−0.0002	0.0001	−0.0004
	(0.053)	(0.105)	(0.001)	(0.001)	(0.0003)	(0.0003)	(0.0004)
Saturated thickness	−0.156	0.475***	−0.001	0.002*	−0.0002	0.00002	0.00004
	(0.146)	(0.150)	(0.001)	(0.001)	(0.0003)	(0.0004)	(0.0004)
Irrigated acres		0.352***					
		(0.050)					
County by year fixed effects?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Well fixed effects?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	14,000	14,000	13,957	13,957	13,957	13,957	13,957
R^2	0.803	0.708	0.612	0.462	0.230	0.248	0.316
Adjusted R^2	0.778	0.672	0.563	0.394	0.134	0.154	0.231

Note: *p<0.1; **p<0.05; ***p<0.01
Standard errors are clustered at the individual level

Table 5: The average (columns 1, 2 and 3) and marginal (columns 4, 5 and 6) effects of the CREP program on water use of the neighboring active wells within 2-mile radius. Columns 1 and 4 show the effects for wells within a 3-mi radius. Columns 2 and 5 show the effects for wells within a 2-mile radius including all the wells that are owned by individuals who enroll a well in CREP. Columns 3 and 6 show the effects for all the wells within a 9-mile radius where all the observation are weighted by the inverse square of the distance.

	Groundwater Extraction (AF)					
	3 mi	CREP	9 mi	3 mi	CREP	9 mi
	(1)	(2)	(3)	(4)	(5)	(6)
Post treatment	−7.986***	−7.234***	−5.050			
	(2.763)	(2.700)	(15.796)			
Number of CREP wells				−1.273***	−0.639	−0.901**
				(0.382)	(0.627)	(0.426)
Growing degree days	−0.145**	−0.040	0.004	−0.154**	−0.045	−0.071
	(0.067)	(0.081)	(0.196)	(0.067)	(0.081)	(0.203)
Growing season precipitation	−0.690***	−0.579***	−0.877	−0.697***	−0.605***	−0.795
	(0.085)	(0.098)	(0.556)	(0.085)	(0.098)	(0.539)
Saturated thickness	0.191	0.403***	1.311***	0.197	0.406***	1.090**
	(0.127)	(0.137)	(0.425)	(0.127)	(0.138)	(0.441)
County by year fixed effects?	Yes	Yes	Yes	Yes	Yes	Yes
Well fixed effects?	Yes	Yes	Yes	Yes	Yes	Yes
Observations	22,500	17,735	58,950	22,500	17,735	58,950
R^2	0.697	0.681	0.907	0.697	0.681	0.907
Adjusted R^2	0.661	0.645	0.897	0.661	0.644	0.897

Note: *p<0.1; **p<0.05; ***p<0.01
Standard errors are clustered at the individual level

Table 6: The average (columns 1 and 2) and marginal (columns 4 and 5) effects of the CREP program on water use of the neighboring active wells within 2-mile radius. Columns 1 and 4 show the effects including the square of the saturated thickness. Columns 2 and 5 include well identifier as the unit of observation rather than longitude and latitude. Column 3 shows the effect of an additional acre-foot retired. Column 6 shows the effects of the ratio of the wells retired.

	Groundwater Extraction (AF)					
	(1)	(2)	(3)	(4)	(5)	(6)
Post treatment	−8.115***	−9.092***				
	(2.797)	(2.843)				
AF retired			−0.004**			
			(0.002)			
Number of CREP wells				−1.021*	−1.746***	
				(0.620)	(0.633)	
Ratio of CREP wells						−51.655**
						(22.571)
Growing degree days	−0.055	−0.089	−0.099	−0.062	−0.098	−0.097
	(0.092)	(0.090)	(0.092)	(0.092)	(0.090)	(0.091)
Growing season precipitation	−0.651***	−0.696***	−0.724***	−0.674***	−0.715***	−0.731***
	(0.107)	(0.109)	(0.107)	(0.106)	(0.108)	(0.108)
Saturated thickness	1.908***	0.401***	0.398***	1.896***	0.413***	0.411***
	(0.337)	(0.151)	(0.151)	(0.336)	(0.152)	(0.150)
Saturated thickness squared	−0.003***			−0.003***		
	(0.001)			(0.001)		
County by year fixed effects?	Yes	Yes	No	Yes	Yes	No
Well fixed effects?	Yes	No	Yes	Yes	No	Yes
Well id fixed effects?	No	Yes	No	No	Yes	No
Observations	14,042	14,042	14,042	14,042	14,042	13,884
R^2	0.700	0.701	0.697	0.700	0.701	0.694
Adjusted R^2	0.663	0.665	0.660	0.662	0.664	0.660

Note: *p<0.1; **p<0.05; ***p<0.01

Standard errors are clustered at the individual level

Table 7: Differences in differences estimates of the effect of CREP enrollment on water use of the active wells that are within the 2-mile radius.

	Groundwater Extraction (AF)		
	2 miles	2 miles	3 miles
	(1)	(2)	(3)
Inside buffer × post treatment	-8.008^{**}	-7.270^{**}	-6.931^{**}
	(3.154)	(3.176)	(2.758)
Growing season precipitation	-0.559^{***}	-0.592^{***}	-0.558^{***}
	(0.036)	(0.025)	(0.032)
Growing degree days	0.094^{***}	0.116^{***}	0.093^{***}
	(0.015)	(0.012)	(0.014)
Saturated thickness	0.381^{***}	0.384^{***}	0.370^{***}
	(0.029)	(0.028)	(0.047)
Year fixed effects?	Yes	Yes	Yes
Section fixed effects	Yes	Yes	Yes
CREP well fixed effects	Yes	Yes	Yes
Other controls		Crop type	
		Technology	
		Conductivity	
		Authorized quantity	
		Longitude, Latitude	
Observations	77,831	65,011	77,831
R^2	0.251	0.255	0.252
Adjusted R^2	0.228	0.227	0.229

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
Standard errors are clustered at the CREP well level

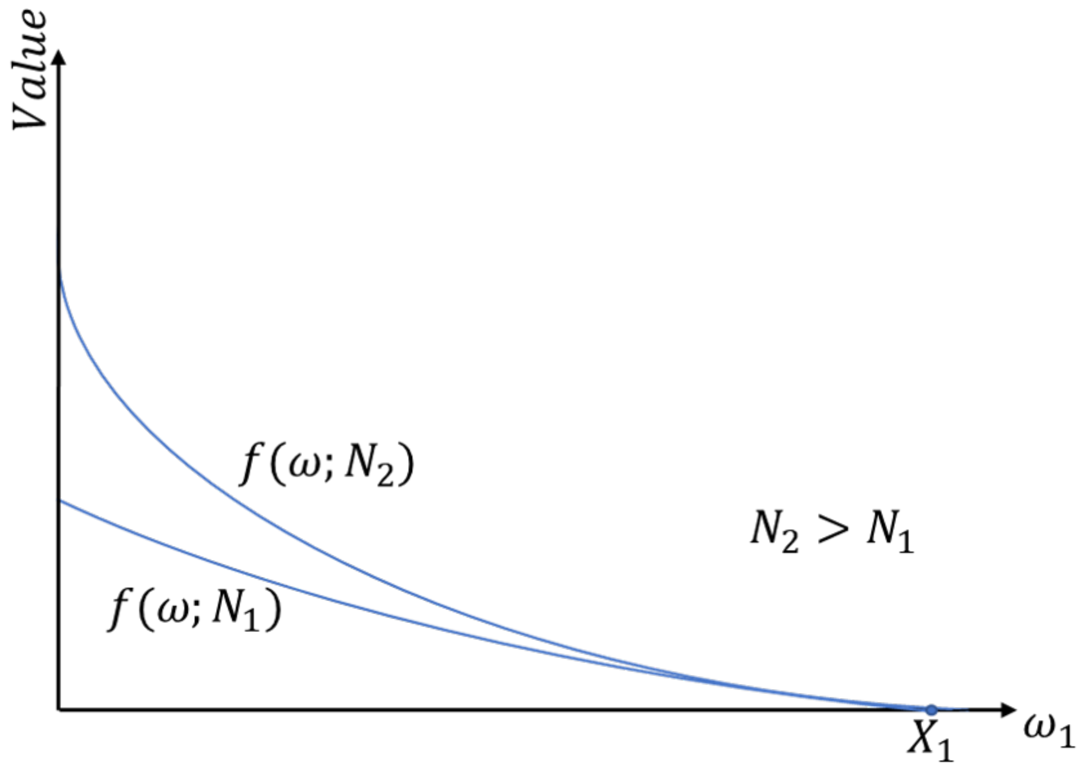

Figure 1: The f function which shows the flow of groundwater from well i to other wells.

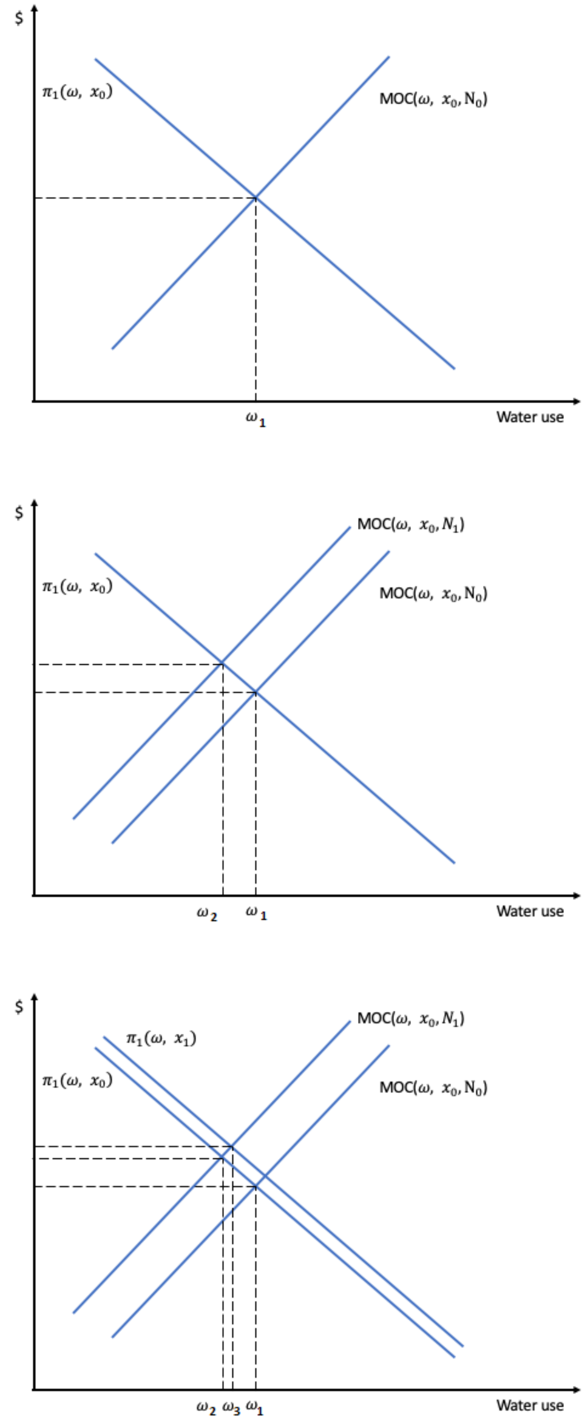

Figure 2: The figure shows the dynamic of groundwater use by active wells. The top figure shows that initially, the profit-maximizing producer sets marginal profit of pumping equal to marginal opportunity cost (MOC) of pumping. The middle figure shows that the producer increases pumping due to less competition. The bottom figure shows that as saturated thickness increases over time, groundwater use goes up again.

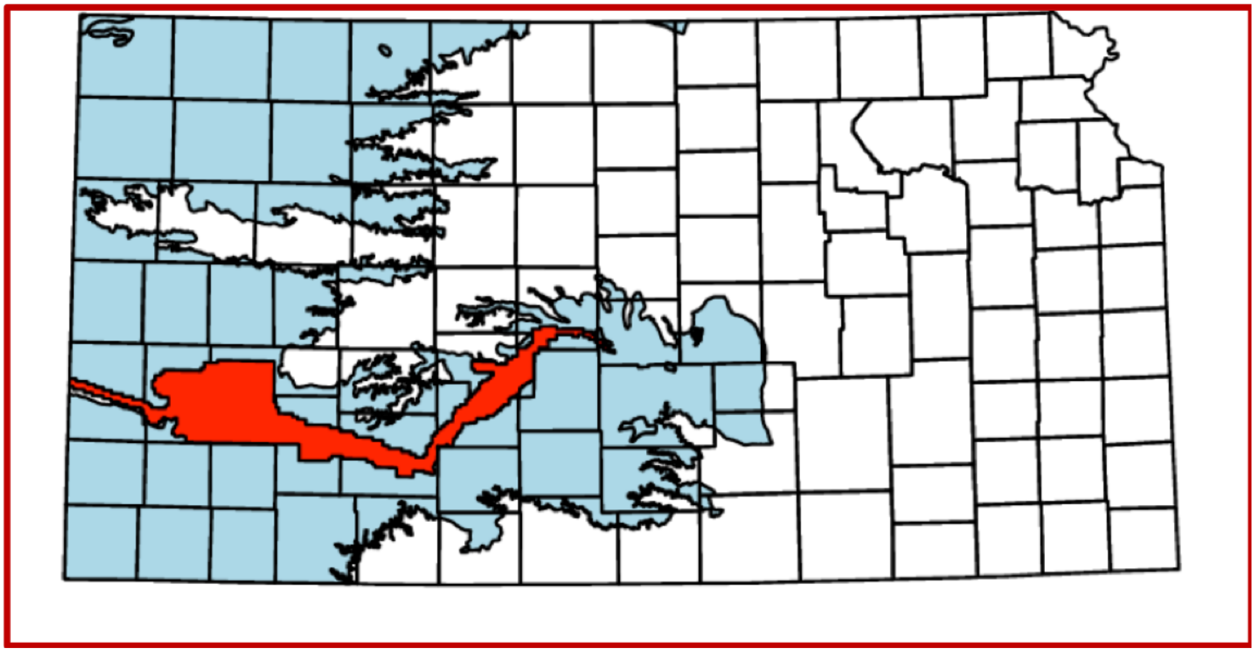

Figure 3: Figure shows counties of the state of Kansas, High Plains Aquifer in light blue, and the UARB CREP area in red.

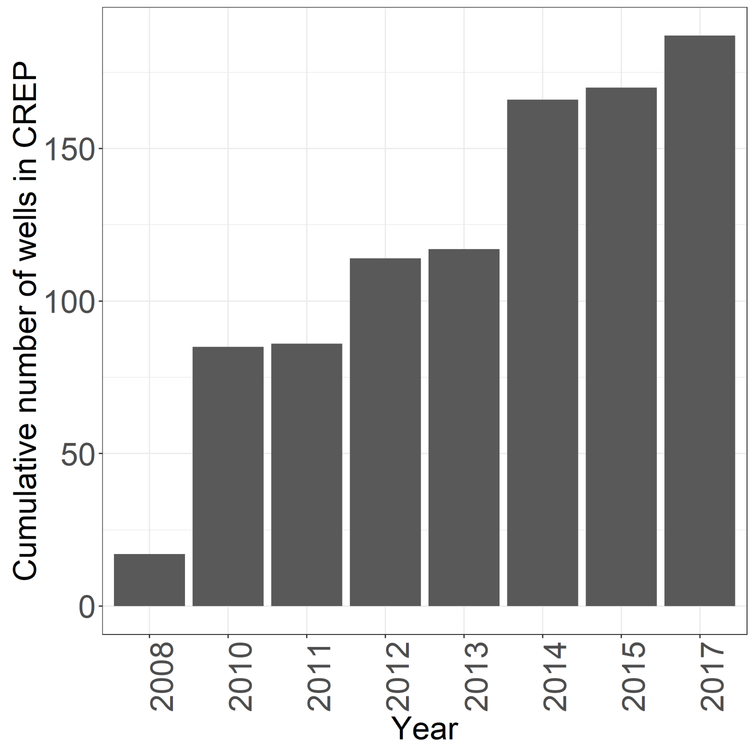

Figure 4: Figure shows the cumulative number of wells that have enrolledi n CREP and shut off their well since 2008.

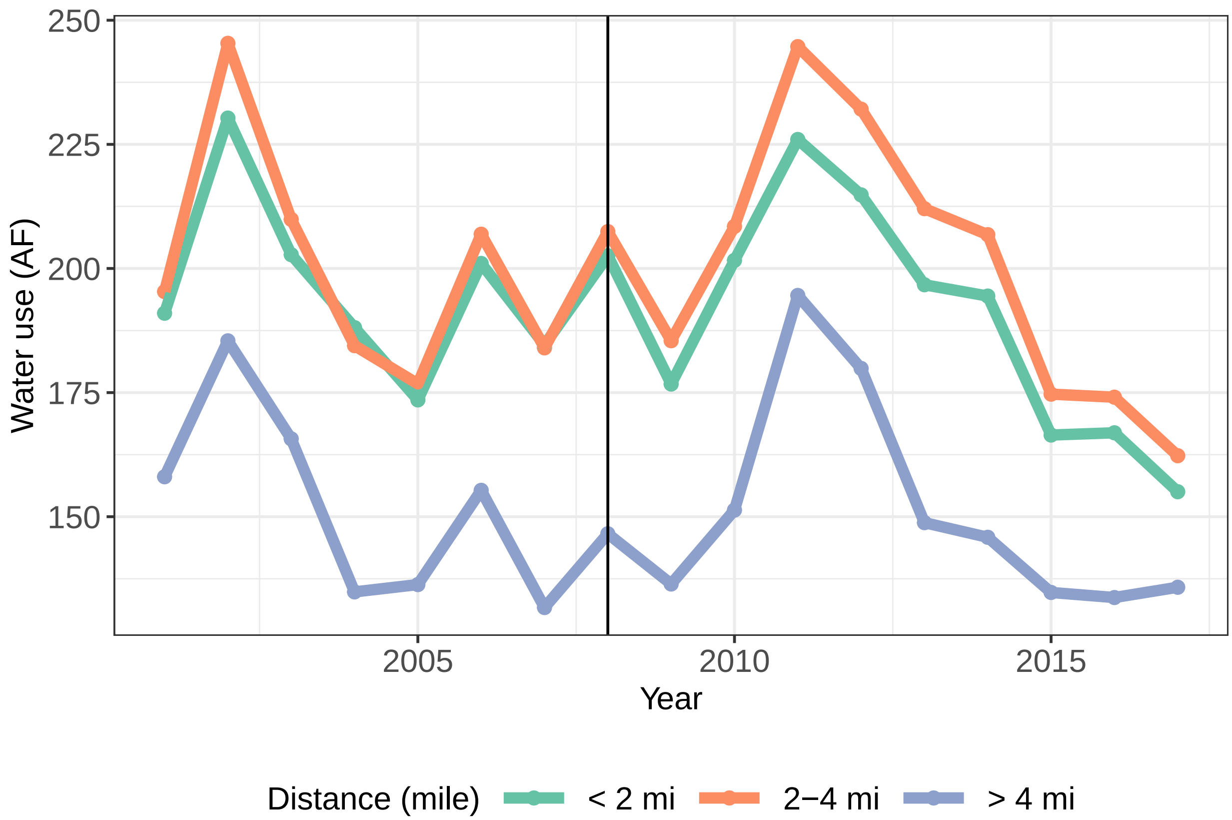

Figure 5: Figure shows average annual groundwater use for wells that are within 1-, 2-, and 3-mile radii of a CREP well.

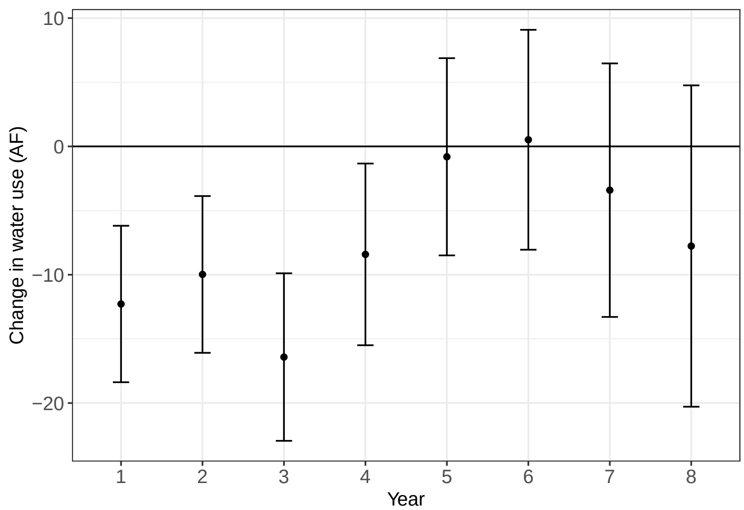

Figure 6: Figure shows the joint estimates of the effects of number of wells enrolled in CREP and years post treatment on groundwater use.

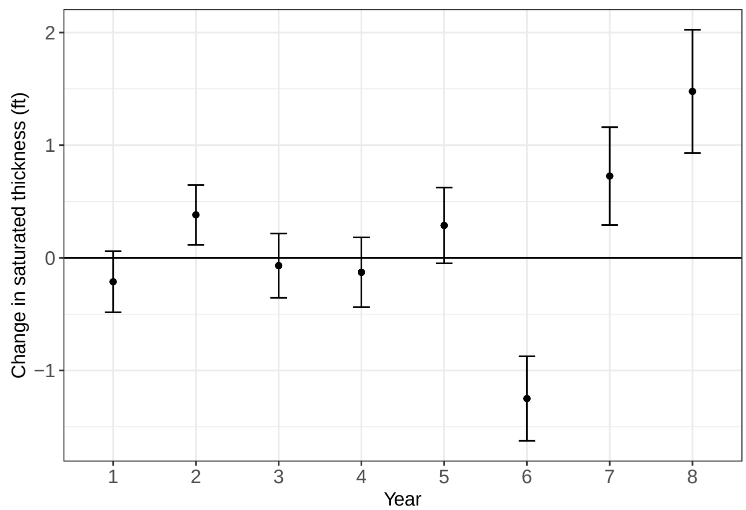

Figure 7: Figure shows the joint estimates of the effects of number of wells enrolled in CREP and years post treatment on saturated thickness.

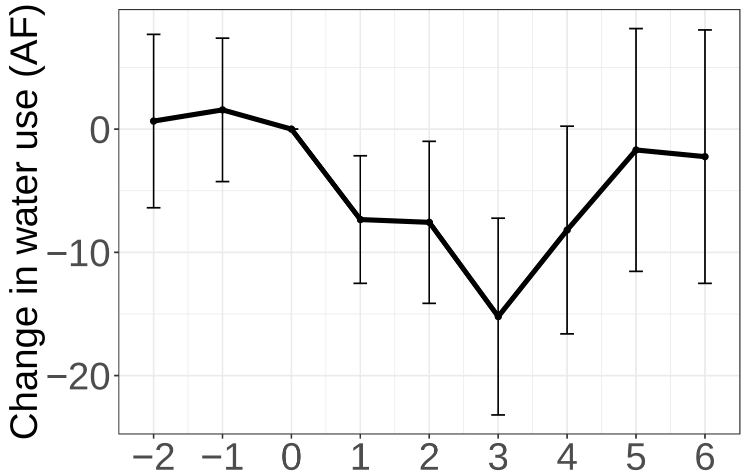

Figure 8: Figure shows water use for wells within a 2-mile radius of the CREP wells for years per and post treatment.

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