Anticipatory Effects of Regulation: The Case of California's Groundwater*

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Abstract

Natural resource management policies often face a long implementation horizon. This can allow for a smooth transition, or alternatively introduce perverse incentives as producers race to extract or establish claims. We study how producers respond to California's Sustainable Groundwater Management Act (SGMA), a major shift in groundwater regulation that does not bind until 2040. We document that investments in perennial crops have increased by nearly 50 percent since SGMA passed in 2014, likely "locking in" water demand and raising future costs of compliance. However, we find that this pattern has occurred despite the policy, not because of it: perennials have in fact increased at a slower rate in regions that expect to face greater future pumping restrictions. Our preliminary results suggest that anticipatory responses can help rather than hinder regulatory implementation.

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1 Introduction

Policies in natural resource management are often implemented over varying time scales. For example, a gas tax hike may occur with fairly little advance notice to drivers whereas carbon targets are set with a long runway. In the latter case, an understanding of both the aftermath and the anticipatory effects are important for policy. A "green paradox" may arise when incentives for anticipatory behavior undermine the goal of an environmental policy (Sinn, 2012). While our theoretical understanding of how preemptive resource extraction is altered by policies and other factors over time is longstanding (Hotelling, 1931), parallel empirical evidence is less common (McDermott et al., 2019; Van der Ploeg and Withagen, 2020).

In this paper, we test how impending groundwater regulation affects agricultural investments in California, where a recently passed legislation requires that excessive drawdown of groundwater be corrected by 2040. The ongoing implementation of the Sustainable Groundwater Management Act (SGMA) of 2014, a rare large-scale policy shock, provides a useful setting to empirically evaluate the anticipatory effects of a natural resource policy. Prior to its passing, groundwater use, with few exceptions, was open access. This regulation required the creation of hundreds of local groundwater management agencies, which together account for over 95% of the groundwater pumping in state, and charged them with halting groundwater depletion in their jurisdictions over a 20 year time horizon. The decentralized nature of the policy, which gives local agencies jurisdiction over implementation in their service areas, provides substantial variation in regulatory stringency across our empirical setting.

California's Central Valley has undergone a major expansion of perennial fruit and nut tree crops over the past couple decades, with implications for water demand (Mall and Herman, 2019).[1] In fact, since SGMA passed in 2014, acreage in perennial crops has increased by nearly 50%. California's top three crops by revenue and acreage – almonds, grapes, and pistachios – are all permanent crops that feature large upfront investments (high initial capital costs plus several unproductive early years) and long productive lives of 25 to 35 years or more. Perennial farmers cannot fallow land in response to drought without incurring large economic losses. As a result, they often elect to pay high prices to secure additional water during water-scarce years, making water demand more inelastic.

In the face of major groundwater regulation, we expect to see anticipatory responses in agricultural outcomes that involve weighing values over long time horizons, namely,

[1] In 2020, pistachios, almonds, and walnut production increased from the year prior by 41, 22, and 20% respectively (CDFA, 2021).

capital investments. Permanent crop acreage is likely to be influenced by information on future water supply (Lobell and Field, 2011; Arellano-Gonzalez and Moore, 2020), and more significant changes are expected in areas facing greater restrictions under SGMA. We anticipate the change in agricultural investments to exhibit one of three patterns. First, it may be that farmers reduce perennial acreage in anticipation of groundwater regulation, converging on the land use allocation that will be optimal in 2040. Alternatively, strategic actors may be racing to establish their claims to groundwater prior to the determination of individual allocations, engaging in perverse preemptive resource extraction and establishing additional acreage in permanent crops before the mandate takes effect. Finally, it may be that the policy is too far away to exhibit near-term effects, suggesting that farmers are delaying the economic costs associated with crop switching that will ultimately need to occur to meet the sustainability mandate.

In a test for anticipatory effects, we consider if SGMA is influencing California's growth in permanent crops using a difference-in-difference design. We compare acreage in perennial cropland across groundwater management agencies that will be subject to greater or lesser pumping restrictions, before and after those policies were first announced. We estimate the average effect of greater pumping restrictions in a two-way fixed effects regression, which controls for time-invariant agency-level characteristics as well as annual shocks common to each agency and its comparison group. We then consider effects over time in an event study framework.

Results suggest that in the post-SGMA period, growth in perennial acreage slowed in response to the policy as basins with greater overdraft experienced reductions in the share of perennial acreage relative to GSAs facing less stringent cutbacks. We find that a 0.15 acre-foot per acre decrease in expected future pumping – the average reduction across agencies subject to SGMA – leads to a 9% or 2.6 percentage point fall in the share of acreage planted in perennials for a typical GSA. Results show no evidence of a perverse preemptive adjustment to establish additional permanent crops before the policy comes into effect. But rather, farmers may be exhibiting an early convergence toward the 2040 land use allocation, despite the long implementation timeline. Event study results suggest that farmers began responding as early as 2018.

Many of the world's most productive agricultural regions are experiencing significant declines in groundwater levels and storage (Wada et al., 2010). In addition to the externality issues that arise from the open-access nature of the resource, groundwater also plays a key role in adaptation to climate change because it serves as a buffer to surface water scarcity and variability, reducing drought impacts and weather risk (Tsur and Graham-Tomasi, 1991; Hornbeck and Keskin, 2014). Despite the urgency of groundwater issues, regulation remains rare.[2] California's SGMA has been hailed as a landmark change – a potential model for groundwater management worldwide – and is arguably the biggest statewide regulatory shift in U.S. groundwater history. But its long implementation horizon calls into question when intended agricultural adjustments will actually occur.

Our study sheds light on how farmers are responding in anticipation of the policy, and contributes new evidence on the preemptive effects to environmental policies in the groundwater context. Studies of the green paradox have focused on climate and fossil fuel policy (Lemoine, 2017; Jensen et al., 2020), land development in response to the Endangered Species Act, and fisheries (McDermott et al., 2019). Contrary to the conclusions drawn by this literature, we find no evidence of perverse effects that undermine the policy goal but rather that early adjustments are smoothing the regulatory transition. Explanations may stem from competition and scarcity of the resource, magnitude of the externalities, and market power in the output market (Espinola-Arredondo et al., 2019).

2 Background

The passing of California's Sustainable Groundwater Management Act (SGMA) in 2014 provides an ideal opportunity to study the anticipatory effects of a natural resource policy facing a long implementation horizon. Groundwater reserves in California's Central Valley have been declining over the last several decades, raising fears about the long-term availability of the resource, while perennial acreage has simultaneously been increasing. Groundwater serves as a critical buffer during periods of surface water scarcity, with average use increasing from 40 to 80% of the water supply during drought years.

Passing during the peak of the state's last major drought, California's SGMA provides a statewide framework for local agencies to manage groundwater and bring their basins into balance. It requires groundwater sustainability agencies (GSAs) in overdrafted basins throughout California to reach and maintain long-term stable groundwater levels. Local agencies are given the authority and flexibility to manage the resource however

[2] A largely structural and dynamic literature in groundwater economics seeks to determine if optimal control improves welfare relative to open-access use. Discounting diminishes the importance of higher pumping costs in the future, and when extraction is small relative to the total storage in an aquifer, the gains from management may be negligible (Gisser and Sanchez, 1980; Brill and Burness, 1994). More recent studies have challenged the long-standing notion that gains from optimal groundwater management may be minimal, which lend support for the increasing calls for groundwater regulation (Brozović et al., 2010; Pfeiffer and Lin, 2012; Edwards, 2016; Merrill and Guilfoos, 2017). Examples of groundwater management do exist but are often at local levels and limited to small areas, such as command-and-control policies in parts of Kansas (Drysdale and Hendricks, 2018), price controls in parts of Colorado (Smith et al., 2017) and California (Bruno and Jessoe, 2021), or well drilling moratoria.

they see fit, as long as their approach is documented in a "Groundwater Sustainability Plan" (GSP) outlined and approved by the state. The timeline to do so is determined by a state-designated level of priority. All GSPs for high- and medium-priority basins must be adopted by January 31, 2022. GSAs managing groundwater in high- and medium-priority basins subject to critical conditions of overdraft must adopt a GSP two years earlier, by January 31, 2020. Once they adopt, the plan to reach sustainability by 2040 formally goes into effect.

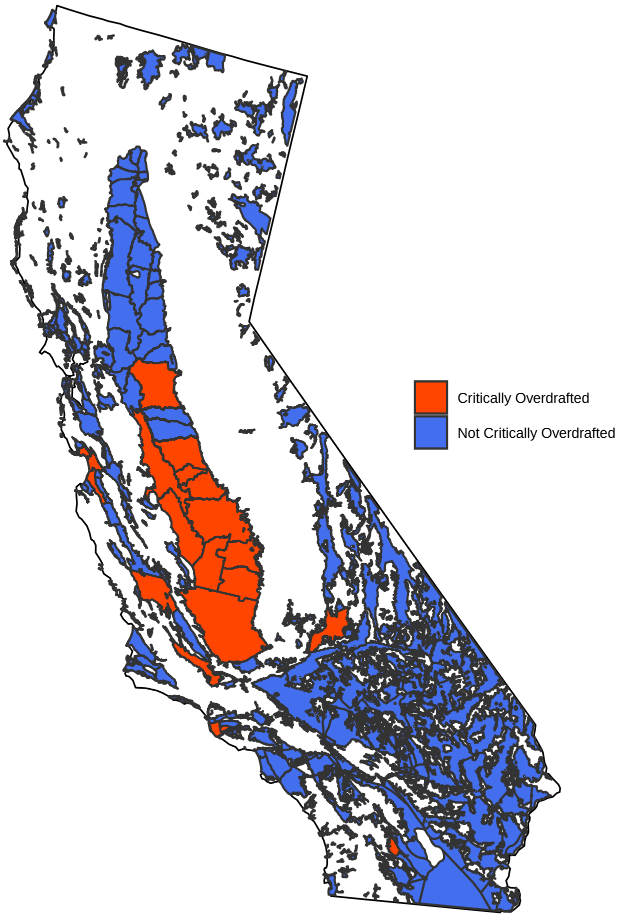
SGMA created substantial variation in regulatory stringency, since basins with more overdraft must adopt greater pumping restrictions in order to achieve sustainability. There were 111 GSAs determined to be of high and medium priority under SGMA, together covering the majority of the agricultural land and accounting for over 95% of the groundwater pumping in the state. Oftentimes, multiple GSAs joined together to collaboratively develop one GSP and were thus treated as the same unit in our analysis. GSAs exclusively covering cities were removed from our sample. Figure 1 shows a map of all groundwater basins in California and distinguishes which are designated as critically overdrafted and subject to a slightly shorter implementation horizon. The subset of these that reside in the Central Valley, shown in Figure 3, form the basis of our analysis and consist of both critically and non-critically overdrafted basins.

2.1 Sustainability as Defined by the Law

Understanding how sustainability is defined and implemented under the law is important for interpreting what it means for farmer's expectations about their future water availability. Sustainability under SGMA is formally defined by the use and management of groundwater in a manner that can be maintained without causing "undesirable results" in regards to six key indicators. The six indicators include (1) chronic lowering of groundwater levels (depletion of supply), (2) reduction of groundwater storage, (3) seawater intrusion, (4) degraded water quality, (5) land subsidence, and (6) depletion of interconnected surface water. Avoidance of these six features to a "significant and unreasonable" degree constitutes a sustainable outcome. Plans are reviewed by the state for comprehensiveness and sufficiency. Inadequate plans are returned for revisions. Failure to comply will result in the state coming in as the backstop and taking over control.

While these six key indicators were determined by the state and are required to be monitored by all GSAs, the precise levels which trigger an "undesirable result" are quantified and set forth by the individual GSA. Each agency's groundwater sustainability plan must detail how they are measuring the indicators and what triggers an undesirable result.

Figure 1: Critical Overdraft Designation of California Groundwater Basins



Note: The figure highlights which groundwater basins were designated as critically overdrafted. Our study focuses on groundwater agencies in the Central Valley, which is where the majority of basins subject to SGMA are concentrated.

In defining what triggers an undesirable result, each GSP must establish minimum thresholds for each applicable sustainability indicator.[3] Minimum thresholds define when the effects become significant and unreasonable, producing an undesirable result, and therefore not achieving sustainability. The minimum thresholds are generally set at, or above, groundwater conditions observed in the basin since 2015.[4] Using a network of monitoring wells, each agency sets thresholds likes these that must be justified reasonably with the best available information and science, else the state can reject it.

2.2 Defining our Treatment Variable

Our goal is to characterize farmers' expectations regarding future groundwater availability due to the passing of SGMA. Our ideal treatment variable would capture the degree to which farmers in an agency's jurisdiction are required to reduce their groundwater pumping in order to achieve the basin's sustainability goals. We construct three different treatment variables that attempt to capture this, each using slightly different information available to us.

Our first treatment measure comes from output from a hydrologic model of surface and groundwater in California's Central Valley. The model estimates a yearly volumetric change in groundwater storage. Using this measure for our treatment relies on the assumption that negative changes in storage must be corrected in order for the basin to achieve sustainability. We then take the total volume and divide it by the acreage of undeveloped area in the GSA to get a per-acre measure of estimated cut-back for agriculture. We refer to this variable as "modeled overdraft." Our second measure of expected future pumping – "reported overdraft"– comes directly from management plans submitted by GSAs which report estimates of average annual volumes of groundwater overdraft.[5] In a similar fashion to the first treatment variable, we divide these annual GSA-level volumes of overdraft by the acreage in the GSA that is undeveloped to arrive at a per-acre estimate of expected agricultural pumping reduction. Finally, for our third treatment variable, we compare direct estimates of current and future pumping as outlined in each GSP. Pulling from each GSP's water budgets for current and future sustainable conditions, we take

[3]For example, an agency may set the minimum threshold for chronic lowering of groundwater levels to be one foot above the groundwater levels observed in 2015 and an undesirable result occurs when 15% or more of the wells in the monitoring network exceeds this minimum threshold.

[4]Plans also contain measurable objectives defined by the GSA, which largely aim to improve groundwater conditions over time. Measurable objectives are more like goals that the agency would like to meet, but, to our knowledge, failing to do so has no consequence.

[5]Each plan contains several water budgets that are based on different subsets of historical data. The plans state their preferred water budget and corresponding preferred overdraft estimate, which we use.

the difference between current and future pumping and again divide this by undeveloped acreage. We refer to this as “projected reduction.”

Our choice to focus on groundwater storage or overdraft to derive our treatment variable is for three reasons. First, it is one of the six sustainability indicators and one that is relevant for all basins subject to SGMA. Contrast this to seawater intrusion or the depletion of interconnected surface water, which are only relevant for basins that are hydrologically connected to the ocean or surface water bodies, respectively. Second, it is a well-understood metric for which there exist several publicly available models that predict basin-level changes in storage.[6] This allows us to calculate our treatment variable in an objective and consistent way across all basins. Some of the other indicators, such as groundwater quality, are more complex to measure, do not have an obvious focal point, and may be measured differently by different GSAs. Finally, the reduction of groundwater storage drives many of the other sustainability indicators, such as land subsidence, degraded water quality, and the depletion of interconnected surface water.

2.3 Timing of Treatment

One complication in our setting is the timing of treatment. We would like to consider a treatment period that corresponds to the time in which farmers changed their expectations about the future availability of water under SGMA. However, we lack complete information on how and when farmers update their expectations. SGMA was passed into law in September of 2014, initiating a timeline for agencies to form and develop groundwater management plans. The deadline for agencies to form was June 30, 2017. The formal establishment of these GSAs and their boundaries determined which jurisdiction a given parcel of farmland falls within. Given this timeline, we consider treatment to have occurred from 2015-2019. In our analysis, we therefore consider 2014 to be the last pre-treatment year and 2020 to be the first post-treatment year.

While a fully informed landowner may understand the consequences of SGMA passing in 2014, one concern is that other landowners may not have been aware of the changing regulatory landscape and its consequences. This concern is mitigated by the fact that community outreach and engagement were codified into the law. In fact, GSAs were required to record their public outreach efforts. With effective stakeholder engagement on behalf of the GSAs, including the dissemination of resources regarding SGMA implementation and several public comment hearings at the local level, it is likely that landowners

[6]Storage and overdraft are conceptually very similar, however one incorporates lateral flow. Overdraft tells us the difference between pumping (out) and recharge (in), net of lateral flows.

successfully updated their expectations about changes to future pumping during this four year period.

2.4 Expectations for Land Use Adjustments

The historical open access nature of groundwater has provided farmers a practically unlimited buffer to variability in the surface water supply, which in California, is largely driven by drought-induced variation in the Sierra Nevada snowpack. Restricting groundwater use may expose farmers to drought risk in a new way. Models of perennial or annual crop adoption in the face of increased drought risk suggest that SGMA should lead to a contraction of area in perennial crops by 2040 (Arellano-Gonzalez and Moore, 2020; Feinerman and Tsur, 2014). However, these models are not equipped to predict anticipatory cropping decisions in advance of a shock to drought risk.

The effects of impending SGMA regulation on land use today are ambiguous. The policy's long implementation horizon can allow for a smooth transition, or alternatively introduce perverse incentives as producers race to extract or establish claims to groundwater in the initial years. It may be that farmers engage in strategic behavior to influence the initial allocation of groundwater pumping rights by staking their claim early on.

3 Data and Descriptive Statistics

The primary data for this analysis consist of annual basin-level groundwater overdraft volume estimates and remotely sensed spatial land use information for all agricultural land in California subject to SGMA. Additional data were collected from GSPs.

3.1 Groundwater Overdraft and Expected Pumping Reductions

Our treatment variables are proxies for farmers' expectations of their future per-acre pumping restrictions. We collected measures of basin-level groundwater overdraft to proxy for the projected change in groundwater pumping expected under SGMA from two sources: Groundwater Sustainability Plans submitted by GSAs and the 1.0 version of the Fine Grid California Central Valley Groundwater-Surface Water Simulation Model (C2VSim), hydrologic model available from the California Department of Water Resources. We aggregate gridded values to GSAs by summing over all model grid cells whose centroid falls within each GSA boundary. The recent change in storage was compared to the average value of the change in storage from the 26 year period preceding

SGMA – 1991 to 2015. Likewise, GSPs estimate and report overdraft as well as current and future pumping, which we used in a similar fashion. We assume farmers use this information to form expectations about future reductions in pumping required to achieve sustainability.

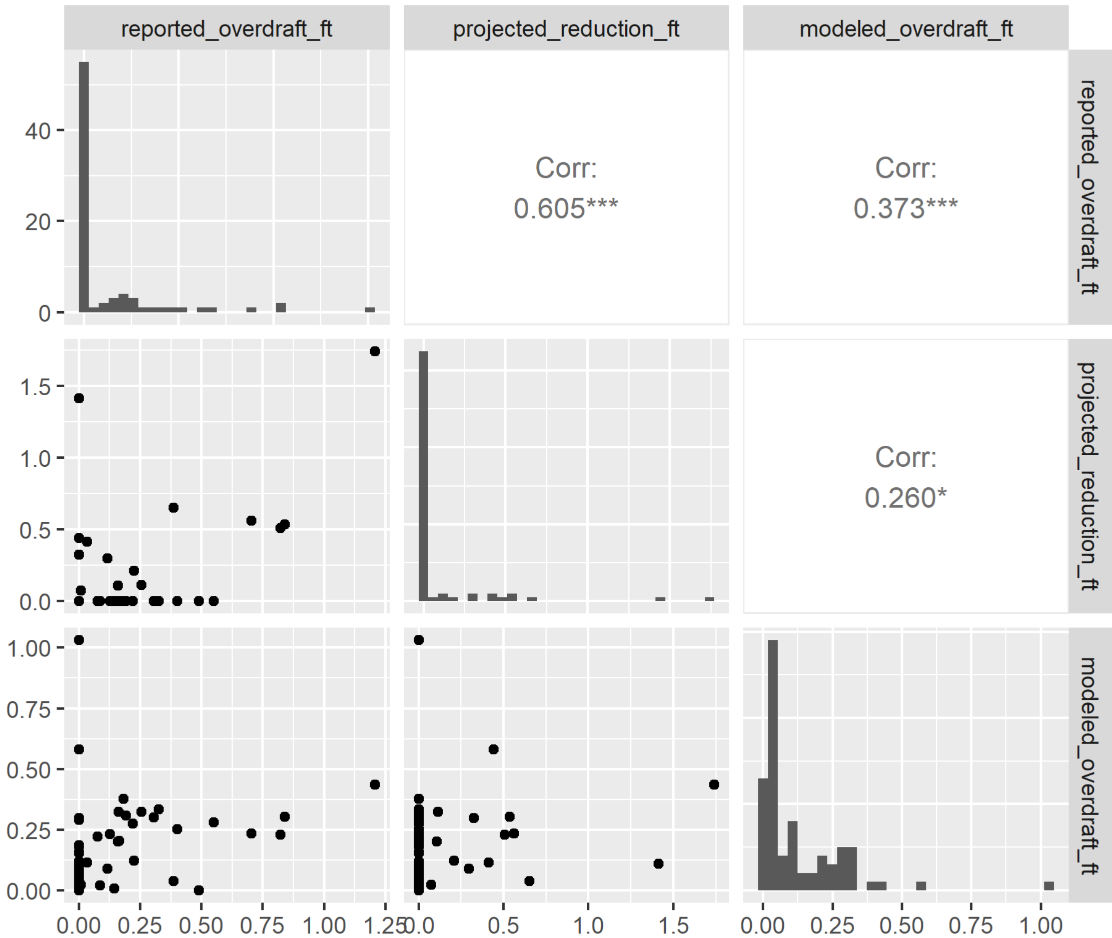
These measures result in three different treatment proxies: (1) the plans' preferred and reported measure of annual overdraft, (2) the plans' projected reduction in pumping, estimated from the different between current and future pumping as reported in the GSP, and (3) the C2VSIM model's estimate of overdraft. All treatment variables are divided by GSA cropland area to obtain per-acre volumes. Figure 2 plots the distribution of these estimates (acre-feet per undeveloped acre per year) for each treatment variable along the diagonal. Scatter plots and correlation coefficients are shown and reported, respectively, for each combination of proxies on the off diagonals. Correlations among proxies reveal a common signal, yet high uncertainty. Projected reduction and reported overdraft – the two treatment variables derived from GSPs – are most highly correlated with each other. Modeled overdraft from C2VSIM features a greater spread but is still positively correlated with the other two treatment variables. Our preferred approach is to average across the three proxies, which yields the treatment variable shown in Figure 3. The estimated reduction in groundwater extraction under SGMA ranges from 0 to 1.2 AF per acre and averages 0.15 AF per acre. For context, California crops like fruits, vegetables, and nuts can use 1.5 to 4 AF of water per year depending on the crop.

3.2 Trends in Land Use

Our land use data consist of annual information on crops grown in the state at a 30-meter grid resolution spanning 2007-2021. We use the USDA's Cropland Data Layer, which is a remotely sensed data product of 119 distinct land-use classifications. Pixels are aggregated to farm fields as defined by quarter-quarter sections in the Public Land Survey System to reduce noise and computation time. Land use is classified into five categories: annual crops, perennial crops, fallowed/idled land, grassland, and nature.

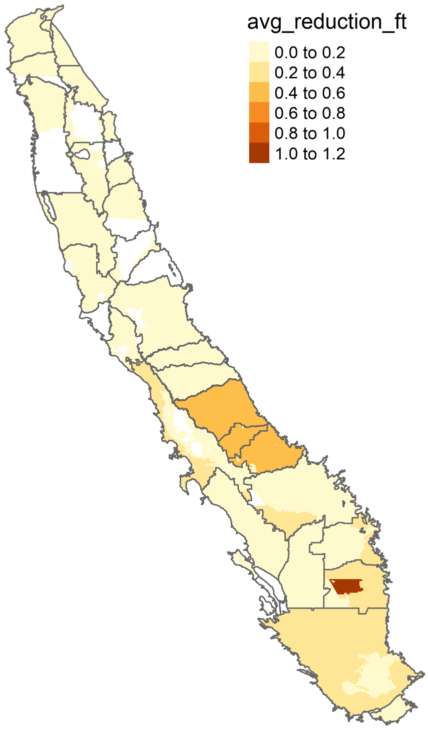
Figure 4 plots trends between annual and perennial crops over the 15 year period from 2007 to 2021. Throughout our sample, we observe a trend of annual acreage declining and perennial acreage increasing. This trend is visible in years prior to the passing of the SGMA legislation. The drop in annuals appears to have leveled off in the initial years after the announcement of the policy before continuing a downward trend in recent years. Perennial acreage has steadily increased since 2010, roughly doubling over a 10 year period with no visible changes in the trajectory in the years after SGMA. In fact, these

Figure 2: Three Treatment Variables



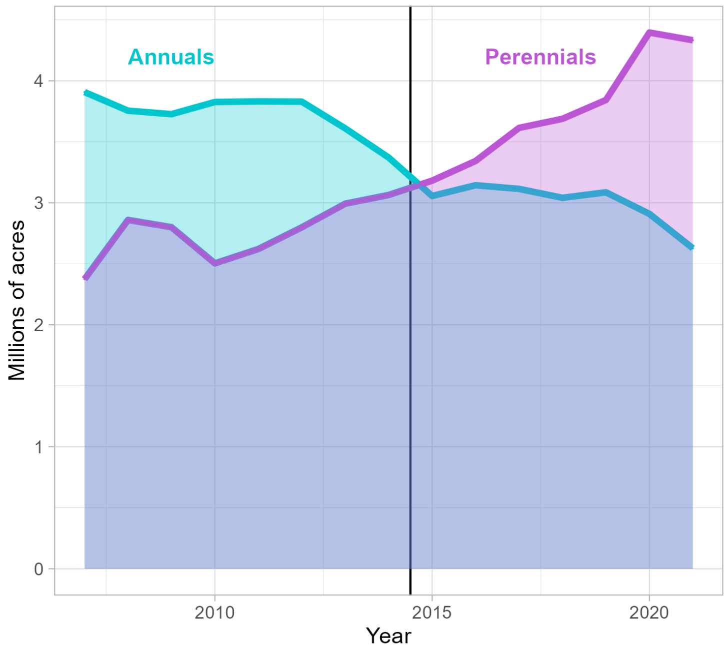
Note: Three treatment variables were constructed to capture the expected reduction in pumping at the GSA level: (1) reported overdraft from GSPs, (2) reported differences between current and future pumping from GSPs, or "projected reduction" and (3) estimated overdraft from the hydrologic model, C2VSim, referred to as "modeled overdraft." The figure plots the distribution of these estimates (acre-feet per undeveloped acre per year) for each treatment variable along the diagonal. Scatter plots and correlation coefficients are shown and reported, respectively, for each combination of proxies on the off diagonals.

Figure 3: Spatial Variation in Regulatory Stringency



Note: The map shows average expected reduction in groundwater pumping required under SGMA in acre-feet per acre for basins in the Central Valley. This average reduction is estimated by averaging across the three treatment variables: reported overdraft, projected reduction, and modeled overdraft. Across GSAs, we calculate that average expected future pumping reductions equal 0.15 acre-feet per acre.

Figure 4: Annual and Perennial Acreage in California Basins Subject to SGMA

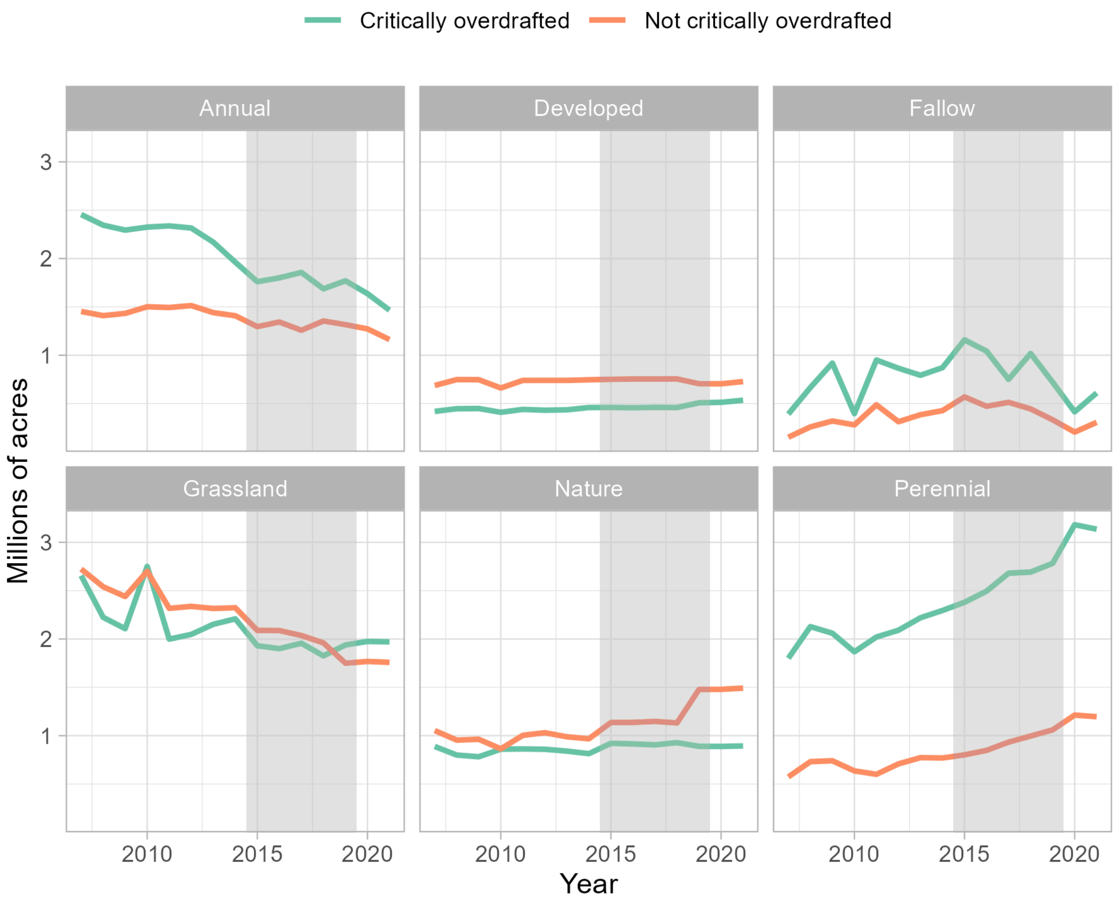


Note: The figure reports acreage of annual and perennial crops in our sample of California groundwater basins over time. The vertical line denotes 2014, the year in which SGMA was announced. Data come from USDA's Cropland Data Layer.

data show that perennial crops have increased nearly 50% since SGMA passed in 2014.

To explore the potential impacts of SGMA we start by plotting changes in land use by basin status for all five land use categories in Figure 5. Changes over time in each of the five categories are separated by whether or not the basin is designated by the state as being in conditions of critical overdraft, which suggests that the basin will likely need to cut back on groundwater pumping more than those without the designation in order to reach sustainability. These descriptive graphs show that basins of different critical overdraft status have experienced somewhat different trends in land use after SGMA was enacted and sustainability plans were adopted. However, these shares are hard to directly compare, since they began quite differently prior to SGMA, and their trends in levels also appear to have been different. To gain clarity, we turn to an econometric analysis.

Figure 5: Comparison of Land Use Across Time by Critical Overdraft Designation



Notes: Trends in land use, expressed in millions of acres, are shown separately depending on whether the basin is designated as critically overdrafted or not. The sample is restricted to land within GSAs whose subbasins were defined as medium or high priority in either 2014 or 2018. Years in which future pumping restrictions were being determined – from the passing of SGMA in mid-2014 to the drafting of plans in 2018 – are grayed out.

4 Empirical Approach

SGMA has created substantial variation in future regulatory stringency across groundwater basins in California. This variation provides an opportunity to learn about how future regulation affects agricultural investment decisions today.

4.1 Estimating Treatment Effects

To estimate the land use effects of future groundwater regulation, we use a difference-in-differences approach, comparing outcomes across GSAs subject to greater or lesser future pumping restrictions, before and after the restrictions became known. To select time periods for the before-after comparison, we want to isolate periods that are completely unaffected by SGMA, and those during which the future pumping restrictions are clear. Since SGMA passed in late-2014, we define the pre-period as ending in 2014. GSAs were initially formed in 2017, but it was not until 2018 that sustainability plans were drafted and public hearings held. Therefore, we exclude the period 2015-2019 and define the post-period as 2020 onward. Because the timing of our treatment variable is simultaneous across all units, we avoid many of the problems identified in the recent literature on difference in differences (Baker et al., 2021).

We regress the natural log of the share of perennials (GSA g in year t) on a measure of the expected future pumping restrictions scaled by total basin-wide pumping, T_g, interacted with time period indicators:

$$\log Y_{gt} = \alpha_g + \lambda_t + \beta_1 T_g \times Post_t + \beta_2 T_g \times Middle_t + \varepsilon_{gt} \tag{1}$$

where Y_{gt} is the perennial acreage in GSA g divided by the total acres in GSA g in year t.

Our parameters of interest β_1 and β_2 capture the average effect of greater pumping restrictions in the post and middle periods, respectively. The post-period indicator is $Post_t = 1(t \geq 2020)$ and the middle-period indicator is $Post_t = 1(2015 \geq t \leq 2019)$. Fixed effects control for time-invariant GSA-level characteristics (α_g), such as soil characteristics, as well as annual shocks shared among all GSAs (λ_t), such as changing market prices for almonds and pistachios. We cluster standard errors by GSA to allow for both serial and spatial correlation.

To parse out effects over time, we deploy an event study framework and estimate the effects on the log share of perennial crop acreage in each year of our data, before and after SGMA was enacted:

$$\log Y_{gt} = \alpha_g + \lambda_t + \beta_t T_g + \varepsilon_{gt}, \tag{2}$$

where all variables are defined as above except that our coefficients of interest are now the year-specific effects of the treatment variable. SGMA was announced in late 2014, after farmers would have planted and harvested for the year, so we consider 2014 to be the last year prior to treatment.

Our coefficients of interest measure the change in log perennial shares due to a one unit increase in overdraft in each of the years following the announcement of the policy. This allows us to observe how the response evolved during the middle and post treatment years.

4.2 Identification

Identification in our setting requires that in the absence of the sustainability mandate, differences in perennial crop acreage between the treated and counterfactual comparison groups would have remained constant over time. We lean on the panel of land use and test for differences in the log share of acreage planted with perennial crops between treated and control units in the seven year period prior to SGMA. We focus our test for differential trends in logs rather than levels because prior knowledge suggests that perennial planting is more of a multiplicative process than an additive one: places that already have more perennials are more likely to add more of them in response to the economic environment because, for example, soils in those areas are naturally more conducive to growing tree nuts. We believe it is more plausible that in response to price shocks that favor perennials, all areas increase perennials by some percentage rather than some number of acres. As indicated in Figure 5, prior to the passage of SGMA, shares of different land uses appear to have been moving in proportion to each other, rather than in parallel. Therefore, the parallel trends assumption more plausibly holds in logs than in levels.

Figure 6 plots the coefficients on the interaction terms from the estimation of equation 2 as well as 95% confidence intervals. A look at the seven years preceding the passage of the policy reveals no evidence of differential trends in the log share of perennial crop acreage between treated and counterfactual GSAs. In each year prior to the passing of SGMA, we fail to reject that the difference in log shares of perennial acreage across GSAs subject to greater or lesser expected pumping reductions is statistically different from their difference in 2014, the year proceeding the announcement of the policy. The failure to identify a difference in the pre-treatment years provides evidence to support the assumption of that in the absence of the policy, treatment and comparison groups would have trended similarly.

Despite this evidence in support of our identifying assumption, it could still be the case that GSAs subject to greater pumping restrictions would have trended differently after 2014. The middle and post treatment years in our sample mark a tumultuous time for California farmers, many of whom produce goods for international buyers and suffered losses from retaliatory tariffs, port congestion, and continuing supply chain issues. While many of these shocks may have differential effects on growers of different crop types, they are unlikely to be correlated with GSA-level variation in overdraft. Other factors, however, may be correlated with both groundwater overdraft and the timing of the policy. For example, it may be that differential access to surface water, which coincides with drought years in our post-treatment period, may be correlated with expected future reductions. In future work, we plan to modify our main estimating equations to further condition on relevant time-varying GSA-level covariates.

5 Results

Table 1 presents results from the difference-in-difference regression shown in the previous section. We estimate the average effect of future groundwater restrictions on the log share of perennial acreage using our preferred treatment variable that averages the expected reductions by GSA across the three proxies. Column (1) reports results from the specification in Equation 1 with weights given by total acreage in the GSA. Column (2) reports results from the same specification but instead as an unweighted OLS regression.

Regardless of assumptions on the weighting scheme, we see a meaningful and negative effect of an increase in expected future reductions in groundwater pumping on the share of land planted in perennial crops. In our preferred specification in column (1), we find that a 1 AF/acre expected reduction in pumping leads to a 0.99 log unit (or $e^{-0.99} - 1 = 63\%$) decrease in the share of perennial acreage. This is a large number, but so is a 1 AF/acre expected pumping reduction. Of GSAs with positive expected future pumping reductions in our data, the average amount of these expected reductions is 0.15 AF/acre. That means that for a typical GSA affected by SGMA, our treatment effect translates to a 9% reduction in the share of perennial acreage, moving the total perennial acreage share from 28% to 25.4% on average.

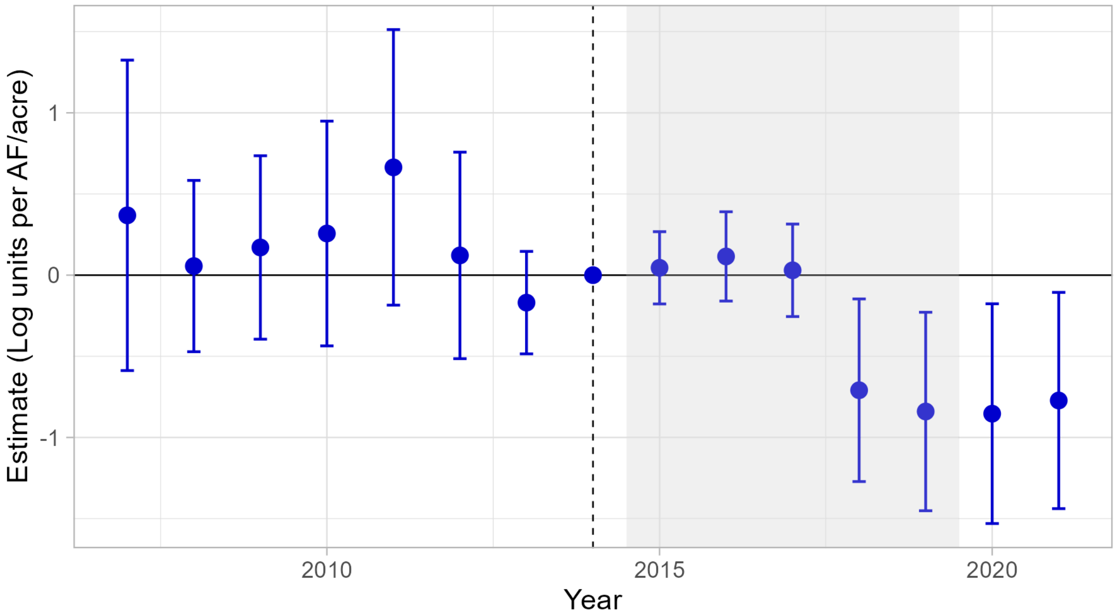
Negative and significant effects are also observed in the middle period spanning 2015 to 2019, suggesting that farmers started to respond to expectations of reductions prior to the official formation of GSA plans. In the years spanning 2015 to 2019, we see that a 1 AF/acre decrease in expected future groundwater translates to a 39% decrease in the share of perennial acreage. This translate to a 5.8% decrease in perennial shares for a typical GSA, which is smaller in magnitude than what we observe in the post period. General

Table 1: Impact of Future Pumping Restrictions on Perennial Acreage

	log(*share_perennial*)				
	(1)	(2)	(3)	(4)	(5)
avg_reduction × post	-0.993***	-1.16***			
	(0.303)	(0.399)			
avg_reduction × middle	-0.489***	-0.516**			
	(0.170)	(0.240)			
projected_reduction × post			-0.322		
			(0.201)		
projected_reduction × middle			-0.167		
			(0.108)		
modeled_overdraft × post				-0.841**	
				(0.335)	
modeled_overdraft × middle				-0.521***	
				(0.169)	
reported_overdraft × post					-0.607***
					(0.189)
reported_overdraft × middle					-0.277***
					(0.099)
GSA fixed effect	✓	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✓	✓
Observations	1,894	1,894	1,894	1,894	1,894
Weights	Acres	None	Acres	Acres	Acres
Clusters	151	151	151	151	151

Note: The table reports results from the estimation of a difference-in-difference regression on the log share of perennial acreage in a GSA. Standard errors, reported in parentheses, are clustered by GSA. The variable *post* is an indicator variable equal to 1 if the year is 2020 or greater. Likewise, *middle* equals 1 for years spanning 2015-2019. All treatment variables are measured in acre-feet/acre. Perennial shares are calculated as the fraction of perennial acres in a GSA relative to the total acreage in a GSA. Significance code: ***: 0.01, **: 0.05, *: 0.1.

Figure 6: Effects of Future Pumping Reductions Over Time



Note: The figure plots differences in the log share of perennial acreage relative to 2014, the year prior to SGMA. Lines denote 95% confidence intervals. Middle years (2015 through 2019) when future pumping restrictions were being determined are grayed out.

trends in groundwater overdraft were well known prior to SGMA and it is probable that some farmers formed early expectations given the severity of overdraft in their regions.

Columns (3) – (5) test the sensitivity of our main estimates to the choice of treatment variable. Each column reports results from the estimation of equation 1 but instead we now replace our preferred average treatment variable with each of the three proxies outlined earlier. We continue to see negative effects of an increase in expected future reductions regardless of our choice of treatment variables. However, treatment effects estimated with the "projected reduction" variable are attenuated. Variables derived from modeled or reported overdraft measures may be more salient than projected reductions calculated from the change in current and future pumping as reported in GSPs.

We next present results on the share of perennial crops over time in an event study framework. Figure 6 presents results from the weighted OLS estimation of Equation 2. The event study framework provides an opportunity to observe how treatment effects evolved over time. A look at the years in the middle period of 2015 to 2019 suggests that the average effect observed in Table 1 is driven by the negative effects observed in 2018 and 2019. No measurable difference is observed in the 3 years following the announcement of SGMA. In the post-policy years of 2020 and 2021, we see differences in the log perennial shares between groups that are statistically different from their difference in 2014. Together with the descriptive statistics shown in Figure 4, these results suggest that the 50% increase in perennial acreage observed after 2014 was not likely caused by SGMA, but persisted despite the policy. Our preliminary findings show that perennial acreage increased at a slower rate in regions that expect to face greater pumping restrictions under SGMA and that these effects started to occur in 2018.

6 Conclusion

In this paper, we seek to add to the empirical literature on natural resource policy by estimating the early and anticipatory effects of a comprehensive groundwater policy in the context of California agriculture. The Sustainable Groundwater Management Act of 2014 is a sweeping groundwater regulation that will alter the time path of groundwater consumption and land use in the largest agricultural state in the United States. The comprehensiveness of the policy, affecting over 95% of the agricultural groundwater pumping in the state, is particularly remarkable given the fact that groundwater use was largely open access prior to its passing. It also occurred in the middle of a period of rapid expansion in perennial acreage across California. The policy required groundwater agencies to establish sustainable pumping criteria and develop plans for how to achieve that. However, it leaves unanswered the question of when farmers will make the adjustments necessary to reach sustainability by 2040.

Natural resource policies that face a long implementation horizon can either ease a smooth transition or introduce perverse incentives as produces race to extract or establish claims to the resource. We study how producers respond to groundwater regulation through the lens of long-term agricultural investments: the decision to plant perennial crops. To do so, we utilize spatial land use data for all agricultural parcels subject to the legislation and estimate how farmland investments respond to changes in expectations about future pumping access. The decentralized nature of the mandate led to large variation in expected future pumping restrictions across the state, creating a policy experiment to study questions about long-term agricultural investments.

We first document that investments in perennial crops have increased by nearly 50% since SGMA passed at the end of 2014. Since perennial farmers cannot fallow land in response to drought or groundwater restrictions without incurring large economic losses, this is likely "hardening" water demand and increasing the future costs of compliance. However, we find that this increase in perennial acreage has occurred despite the SGMA policy, not because of it. Controlling for time-invariant agency characteristics and annual shocks, we find that a 0.15 acre-foot per acre decrease in expected future pumping is leading to a 2.6 percentage point reduction in the share of acreage planted in perennials. Our results tell us that perennial acreage has increased at a slower rate in regions that expect to face greater future pumping restriction under SGMA, suggesting that these anticipatory responses are helping to smooth the transition to SGMA sustainability.

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