The Political Economy of Groundwater Management: Descriptive Evidence from California*

Ellen M. Bruno[†], Nick Hagerty[‡], and Arthur R. Wardle[§]

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Abstract

We use California's Sustainable Groundwater Management Act (SGMA), a statewide framework for local institutional change, to study the drivers of collective action and policy instrument choice over groundwater. We evaluate how SGMA altered the bargaining environment, place it in the context of the literature on the political economy of common-pool resource management, and characterize cross-sectional patterns in proposed demand management strategies. We find that by reducing the costs of collective action, SGMA brought about a significant departure from the prior status quo of open access, with a majority of basins now proposing incentive-based policies for groundwater management. Understanding the political economic forces that explain how, where, and why management is occurring is critical to the sustainability of groundwater-dependent agricultural regions worldwide.

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[†]Department of Agricultural and Resource Economics, University of California, Berkeley. Email: ebruno@berkeley.edu

[‡]Department of Agricultural Economics and Economics, Montana State University. Email: nicholas.hagerty@montana.edu

[§]Department of Agricultural and Resource Economics, University of California, Berkeley. Email: arw@berkeley.edu

1 Introduction

Water pumped from underground aquifers contributes to agricultural production worldwide with particular importance in times of drought. When surface water flows are lower than expected, groundwater resources provide an important reserve capable of decoupling agricultural production from year-to-year variation in precipitation (Tsur and Graham-Tomasi, 1991). With warming temperatures and resulting changes to precipitation and surface water storage due to climate change, agriculture will increasingly rely on groundwater to make up shortfalls in surface water supplies. As a result, both the demand for and buffer value of groundwater will increase. Despite the growing need for groundwater as a tool to adapt to climate change, pumping in excess of recharge threatens the sustainability of groundwater aquifers worldwide (Edwards and Guilfoos, 2021). Persistent drawdown is a particularly acute problem in many of the world's major food-producing regions, including California's Central Valley.

Despite a broad range of available regulatory solutions – from the formalization of property rights to pumping restrictions and volumetric fees – groundwater regulation remains rare. Examples of groundwater management do exist, ranging from quantity controls in parts of Kansas (Drysdale and Hendricks, 2018) to price controls in small parts of Colorado (Smith et al., 2017) and California (Bruno and Jessoe, 2021). Groundwater basins that have instituted rules that bear resemblance to first-best policies have enjoyed greater economic returns from their water as a result (Hornbeck and Keskin, 2014; Edwards, 2016; Ayres et al., 2021). But as with any common-pool resource dilemma, groundwater overdraft often continues despite its resulting economic losses due to the difficulty of replacing open-access management with institutions designed to preserve aquifers' value. Challenges arise due to the high transaction costs associated with collective action and the political economic forces that influence policy choice.

Classic characterizations of the groundwater commons dilemma often oversimplify both the problems and remedies facing real-world basins. The tragedy of the commons can be overcome through collective action, but the ability to do so is determined by myriad factors affecting the magnitude and distribution of the gains from management and the costs of bargaining. What prompts groundwater pumpers to attempt collective management, which factors influence the success of those attempts, and what determines policy choices are all central questions in the political economy of groundwater management. Understanding the political economic forces that give rise to collective action and first- or second-best policies is critical to the sustained economic viability of groundwater-dependent regions in the face of climate change.

This paper sets forth a framework for determining the likelihood for collective action and uses this to outline and test five hypotheses in the context of groundwater management in California. Our case study is California's Sustainable Groundwater Management Act (SGMA) of 2014, a landmark statewide mandate for local institutional transition. SGMA required the formation of hundreds of local Groundwater Sustainability Agencies (GSAs), formed by coalitions of pre-existing water and land management agencies like water districts, cities, and counties, and charged each GSA to develop management actions to meet sustainability criteria. By mandating sustainability, SGMA forces parties to negotiate and therefore reduces barriers to collective action that would have persisted in the absence of the law. We construct a novel dataset on the management choices, environmental conditions, and governing structures of 343 groundwater agencies subject to the legislation and use it to characterize cross-sectional trends in collective action and management strategies across the state.

California's SGMA offers a unique real-world setting for describing changing institutions and investigating determinants of collective action and policy instrument choice. Affecting hundreds of groundwater agencies simultaneously, the legislation covers all major agricultural areas, which account for over 90% of the state's groundwater pumping, in the nation's largest agricultural state.[1] Second, SGMA provides a statewide framework with local authority and flexibility, while requiring that groundwater agencies engage with the public and document their governance structures and intended management actions. In essence, SGMA reduces the transaction costs to bargaining over collective action, empowers local water agencies to manage groundwater with new authorities, and requires that their processes and actions be recorded publicly. While it is still early in the process, California's initial implementation of SGMA offers a rare look at the barriers to collective action and the drivers of policy instrument choice.

Our assessment reveals a significant departure from the prior status quo of open-access groundwater use. We find that two features are positively correlated with an increased likelihood of collective action: more severe groundwater depletion and less heterogeneity among resource users in a locality. Contrary to expectations, a higher number of bargaining parties is not associated with a decreased likelihood of active groundwater management. Additionally, we find that agencies are approaching groundwater sustainability with substantial policy heterogeneity across the state by proposing a mixture of price and quantity instruments as well as a suite of other conservation incentive programs and ad-hoc pumping restrictions. The most common proposed policy change is an introduction

[1] Groundwater makes up 40% of the agricultural water supply on average in California, but can be a much larger portion during dry years.

of taxes or fees, for which 60% of management plans stated a plan to implement or consider such a change. Almost half of the submitted plans include allocations to determine individual pumping limits, and two-thirds of the agencies setting allocations are considering trade of those individual allocations. Using constructed measures of local political power and local heterogeneity in groundwater demand, we find that proposals to allow trade of allocations are more likely when plans are governed by a board with a greater share of representation by agricultural interests (through special districts) and that this appears to better predict planned trading programs than a proxy for the available gains from this instrument.

This paper contributes to the literature on how groundwater management institutions develop in light of new empirical evidence offered by SGMA. The literature describing the political economy of this type of institutional transition is thick, but many open questions remain due to the inherent difficulty of collecting adequate data in these contexts. Most closely related to this work are Leonard and Libecap (2019) and Ayres et al. (2018), both of which study institutional transitions of common-pool water resources and attempt to explain the economic characteristics that lead to institutional change. By compiling a new dataset on the management choices, governance, and economic and hydrologic features of hundreds of agencies following the passing of a statewide legislation that substantially altered the bargaining environment over collective action, we are able to present new evidence on where, how, and why groundwater management is occurring in practice.

California's approach to groundwater management through SGMA provides lessons for other regions facing similar common-pool resource issues. Our analysis reveals a state-led process to empower local agencies to collectively take action via a unifying framework that served to reduce bargaining costs. The state was effective at reducing the transaction costs associated with collective bargaining by improving access to information, altering the policy default, influencing the number and composition of bargaining parties, and providing direct financial support. Other regions looking to incentivize collective action at the local level could look to California's SGMA. The fact that we see substantial heterogeneity in policy instrument choice across space suggests that a uniform top-down approach may not allow local agencies to adopt preferred policies that reflect diverse regional hydrologic and economic conditions.

The rest of the paper proceeds as follows. We first provide background on SGMA. In Section 3, we develop a conceptual framework for both overcoming the open-access problem and the criteria for policy instrument choice. We provide an overview of the political economy literature regarding what stands in the way of effective management and outline five testable hypotheses. Section 4 describes the data. Section 5 presents empirical results that document patterns in how the GSAs are planning to meet the sustainability requirements and in local characteristics that predict the chosen strategies. The final section concludes.

2 The Sustainable Groundwater Management Act

Groundwater serves as a critical buffer during periods of surface water scarcity, with average use in California increasing from 40 to 80% of the water supply during drought years. 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.

The passing of California's Sustainable Groundwater Management Act (SGMA) in 2014 provides an ideal opportunity to study the political economy of a groundwater regulation in its early implementation stage. Passing during the peak of the state's last major drought, SGMA provides a statewide framework for local agencies to manage groundwater and bring their basins into balance. It requires stakeholders in overdrafted basins throughout California to reach and maintain long-term stability in their groundwater levels by either 2040 or 2042, depending on their priority status. Local management authority is assigned to new groundwater sustainability agencies (GSAs) that were required to be formed in each basin or subbasin by 2017.[2] GSAs are given the authority and flexibility to manage the resource however 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 adhere to SGMA is determined by a state-designated level of priority. Based on current conditions of groundwater overdraft, DWR assessed whether each basin was experiencing "critical overdraft," which bumps major SGMA deadlines up by two years. Based on a much wider suite of variables, such as expected future population growth, DWR also separated each groundwater basin into High, Medium, Low, or Very Low priority. Only high- and medium-priority basins face most of SGMA's mandates. All GSPs for the 94 high- and medium-priority basins were required to be adopted by January 31, 2022. GSAs managing groundwater in high- and medium-priority basins subject to critical conditions of overdraft had to adopt a GSP two years earlier, by January 31, 2020.

[2]We will use "basins" to refer to the basic spatial units of management under SGMA, which DWR calls basins and subbasins. A basin is an entire aquifer that is relatively physically isolated from other groundwater resources; many large basins are further divided into subbasins. Basin and subbasin boundaries were developed by California Department of Water Resources (DWR) for other purposes prior to SGMA and are not influenced by local choices. Each basin (i.e., or subbasin) is required to form at least one GSA; GSAs never contain parts of more than one basin, but one basin may have more than one GSA. In some cases, multiple GSAs within a basin joined together to collaboratively develop one GSP; our analysis treats them together as one unit.

Once they adopt, the plan goes into effect. The state provided both advisory and monetary resources for the development of plans. Failure to comply will result in top-down state regulation as a backstop.

SGMA created substantial variation in regulatory stringency, since basins with more overdraft must adopt greater pumping restrictions in order to achieve sustainability. Figure 1 shows the state-designated priority level, including which basins were deemed to be in conditions of critical overdraft.

Recognizing the institutional and policy path dependence in which SGMA emerged is important for characterizing the local developments and management strategies we observe. While historic in its nature to mandate groundwater management statewide, SGMA naturally built upon decades of previous water policies designed to support and encourage groundwater management (Ayres et al., 2018; Dennis et al., 2020). Its emphasis on local control, giving the newly formed GSAs the authority to leverage fees and facilitate trade, reflects a history of groundwater measurement and management at the local level. Prior to SGMA, the state provided funds to local water agencies to monitor groundwater and conduct studies, entrenching this idea of local control (Dennis et al., 2020). Some water agencies and irrigation districts took advantage of these incentives and others did not, placing agencies at different starting points when SGMA was passed.

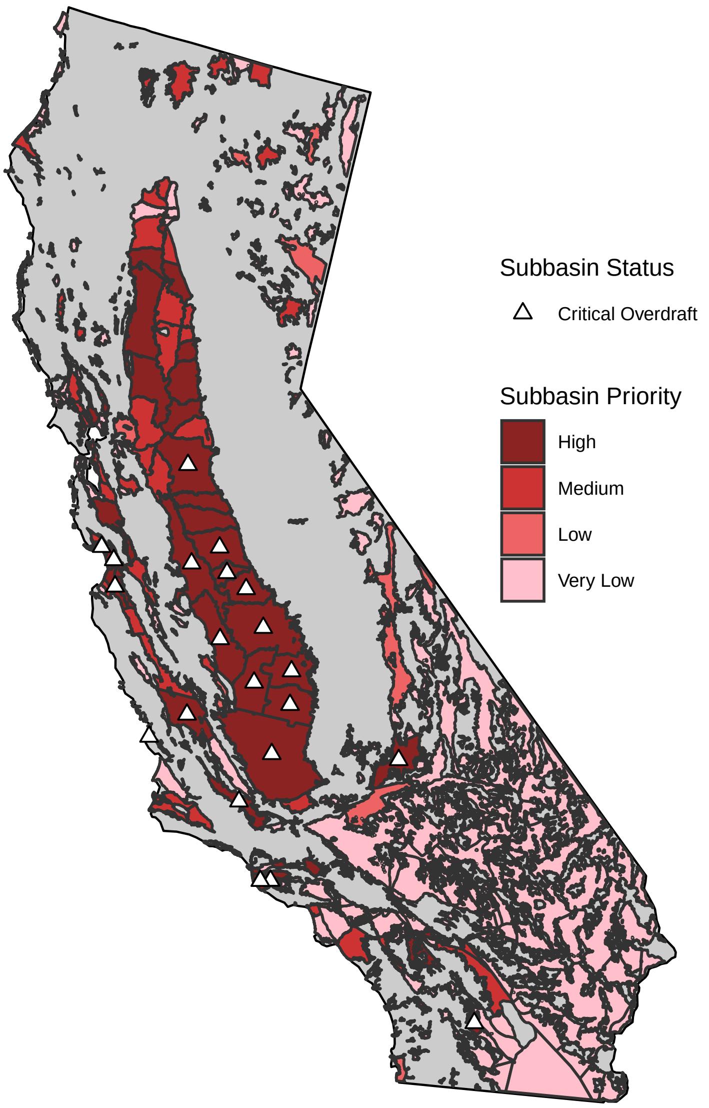
2.1 Changes to the Bargaining Landscape

The passing of SGMA changed the bargaining landscape in several important ways that are relevant for the emergence of collective action. Prior to the passing of SGMA, active groundwater management was only occurring in a small number of adjudicated basins (Ayres et al., 2018), implying that in most cases the transaction costs of bargaining outweighed the gains from management, despite stark declines in groundwater reserves in many regions.[3] We see SGMA serving to enable less costly institutional transitions, pulling some basins into collective action and active groundwater management. We anticipate that GSAs will introduce meaningful groundwater management where the transaction costs associated with bargaining over collective action are now smaller than the gains from management (Demsetz, 1967).

SGMA has altered the bargaining environment in four key ways. First, SGMA serves to lessen information asymmetries and incomplete information by requiring hydrologic modeling and the development of a detailed water budget that must be consistent with

[3]Given that court adjudication is often a decades-long and highly litigious process, this may not be surprising.

Figure 1: Priority and Overdraft Designation of California Groundwater Basins



Note: High- and medium-priority basins are subject to SGMA and must write GSPs. These are concentrated in the Central Valley. Critically overdrafted basins are subject to an earlier compliance timeline.

other GSPs in the same basin. It also requires the establishment of a monitoring network of wells to track key sustainability indicators. Combined with its requirements to conduct public outreach and stakeholder engagement, this likely reduced information barriers to collective action.

Second, SGMA generates a new role for the state to act as a backstop if plans are insufficient, altering the policy default, and reducing the likelihood of management plans that lack teeth. By imposing a 2040 sustainability mandate, SGMA restricts the set of potential collective agreements, eliminating the possibility that parties come together and decide that business-as-usual is their mutual best interest.[4]

Third, SGMA broadens the jurisdiction and power of local agencies by giving them the new authority to monitor and meter wells, levy taxes, and facilitate groundwater trade. It empowers GSA board members to agree on management actions as representatives of the interests in the region, thereby limiting the number of bargaining parties directly involved, and bolstering their ability to conduct effective monitoring and enforcement. Even some "very low priority" basins are forming GSAs and writing GSPs, even though they are not required to do so, implying that these shifts in the bargaining environment have been significant even in instances where there is no new binding sustainability mandate.

Finally, SGMA sinks many transaction costs by mandating the development of plans, which forces negotiation among GSA board members, and by providing direct financial support for plan development.

3 Conceptual Framework

When does effective groundwater management occur, and how? We next review the open-access problem, casting the outcome as an equilibrium result of balancing the gains from management and the costs of collective action. Based on prior literature, we characterize the conditions under which we might expect certain management strategies to emerge. We obtain five testable hypotheses that we take to the early data on SGMA.

3.1 Overcoming the Open-Access Problem

The basic problem facing groundwater management is a tragedy of the commons. With an unrestricted authority to pump from underlying aquifers, individual pumpers choose

[4]We note that DWR cannot perfectly observe or predict whether a given plan will actually achieve sustainability, meaning the state is only likely to reject plans that fail to target sustainability by a large and apparent margin. For this reason, we may expect basins where bargaining costs continue to outweigh the gains from management to propose only a minimal set of actions to appease state regulators.

groundwater extraction based on their own private costs and benefits and ignore the external costs imposed on other basin pumpers through reduced aquifer storage. Choosing to extract additional water today imposes negative externalities on other users, reducing the amount available in the future, increasing pumping costs for neighboring pumpers, affecting groundwater quality, and inducing other spatial environmental effects. In the face of significant costs for bargaining over new management among users, economic theory predicts that individual pumpers will pump individually optimal but socially excessive amounts, leading to long-run drawdown of the aquifer.

The tragedy of the commons can be overcome through collective action, but the ability to do so is determined by myriad factors affecting the magnitude and distribution of the gains from management and the costs of bargaining. Textbook treatments of the commons problem facing groundwater users elegantly describe how individually optimal extraction decisions can be socially suboptimal but oversimplify both the problems and remedies facing real-world basins. What prompts groundwater pumpers to attempt collective management, the factors influencing the success of those attempts, and what determines the choice of management instruments are all central questions in the political economy of groundwater management. Here, we start by describing the commons problem and characterizing the gains from optimal management. We then discuss the drivers of bargaining costs that together determine the likelihood of collective action. We use this framework to outline five testable hypotheses.

3.1.1 Gains from Management

To formalize this notion of the gains from management, consider a basin with many pumpers i, each of whom have a profit function $\pi_i(w_i(t), h(t))$ describing their profit from groundwater use as a function of the volume of water $w(t)$ pumped at time t and the height of the water table $h(t)$. The equation of motion for the height of the water table is $\dot{h}(t) = r(t) - \sum_i w_i(t)$, where $r(t)$ describes recharge.

A benevolent social planner would solve the following problem:

$$\max_{\{w_i(t)\}} \int_0^\infty \sum_i \pi_i(w_i(t), h(t))\, dt$$
$$\text{s.t. } \dot{h}(t) = r(t) - \sum_i w_i(t),\ h(0) = H_0$$

which maximizes collective profits of pumpers on the basin subject to the constraint determining the rate of change in the height of the groundwater table. This is an extremely simplified model, often referred to as the "bathtub" model of groundwater, that abstracts away from the concept of conductivity and other important spatial aspects of the groundwater hydrology that translate to differences in individual net returns from management.

The seminal paper by Gisser and Sanchez using the "bathtub" model found the gains from optimal management to be negligible when extraction was small relative to the size of the aquifer, suggesting small stock externalities (Gisser and Sanchez, 1980). This approach assumes the absence of cones of depression around wells and the sizeable spatial pumping externalities that exist in many aquifers, which increase the gains from coordination and management (Brozović et al., 2010). It has been shown that high hydraulic conductivity and lower recharge are associated with higher relative land value increases when groundwater management is implemented (Edwards, 2016).

All else equal, we expect basins that would experience greater gains from management given a certain set of aquifer conditions to be more likely to experience active demand management under SGMA. We can proxy for the expected gains from management with the degree of current overdraft.

Hypothesis 1 *Basins with greater overdraft will be more likely to adopt a demand management policy.*

3.1.2 Costs of Collective Action

While the gains from management help to determine the likelihood of successful bargaining to end open access, a complete accounting includes the costs of bargaining as well. In principle, transitioning to a more efficient groundwater management policy should produce enough value to compensate any potential losers in the transition; this is the very definition of what it means to be efficiency improving. In practice, determining exactly how new property rights to groundwater ought to work and who should receive the gains and in what shares is a costly process that can spur deep disagreements among bargaining participants.

Both the size and distribution of bargaining costs among users influence the likelihood of institutional change. Once at the negotiating table, users are constrained in what actions they can implement both by their ability to reconcile their heterogeneous preferences and the enforcability of their agreements.[5]

First, resource users need to agree upon baseline information about the nature of the groundwater resource and the value of individuals' claims. With imperfect scientific understanding of the groundwater resource, substantial disagreement over the rate

[5]A complete accounting of the variables influencing the endogenous management process would be beyond the scope of this paper—Ostrom (2009) identifies 53 unique variables important to understanding socio-ecological systems like groundwater.

of recharge, interactions with surface water flows, or the extent of hydraulic conductivity can easily spill over to disagreement over the best course of management action (Wiggins and Libecap, 1985; Ostrom, 1990, p. 33-34). Imperfect and asymmetric information regarding the value of water to different participants can also inhibit defining appropriate compensating transfers to smooth over disagreements (Wiggins and Libecap, 1985; Sallee, 2019). Outright deception in an asymmetric information bargaining environment (for the purpose of securing a larger allocation, for example) further aggravates these problems (Libecap, 1989, p. 26).

The number of bargaining parties also naturally raises the difficulty of reaching agreement. With few participants, norms of interpersonal conduct (Ellickson, 1991) or Coasean bargaining (Coase, 1960) can reliably encourage effective resource management. With larger groups, the complexity of negotiations increases and the scope of potential compensating transfer opportunities shrinks. In the context of settling disputed American Indian water claims, Sanchez et al. (2020) show that the number of bargaining parties increases the duration of negotiations. In the context of oil field unitization, which is highly similar to groundwater management in terms of relevant bargaining characteristics, Libecap and Wiggins (1984) find that only relatively concentrated fields are capable of reaching unitization agreements; fields with multitudes of smaller operators fail to reach agreement and continue overproducing.

Hypothesis 2 *A greater number of bargaining parties increases the costs of collective action and reduces the likelihood of active demand management.*

Heterogeneity among resource users has a more contested influence over bargaining for collective action. Early treatments tended to treat heterogeneity as an unambiguous drag on the bargaining process (Libecap, 1989, p. 22-23). When some users gain substantially from the status quo, disputes between incumbents seeking to maintain their privileges and burgeoning users desiring more equitable resource allocations can derail negotiations. Heterogeneity in terms of identity can also inhibit agreement—where negotiators bring existing socio-cultural resentments to the bargaining table, distrust further narrows the scope of achievable agreements. Varughese and Ostrom (2001) synthesize this literature and find that heterogeneity need not be a barrier to collective action. According to Ruttan (2008) heterogeneity in benefits of management can even facilitate transition to efficient management when "economically advantaged individual(s) gain from providing the collective good, and are thus willing to pay a greater share of the costs [and/or] where the actions of one or a few individuals provide sufficient positive externalities to provide the good for all."

Hypothesis 3 *Greater heterogeneity among bargaining parties can both increase and decrease the costs of collective action, resulting in an ambiguous effect on the likelihood of active management.*

Finally, the broader legal and political environment can both impose limitations and enable further progress on potential collective action agreements. While organizing for collective action completely outside the auspices of government is possible, recognition and support from formal authorities enables a broader suite of monitoring and enforcement possibilities.

3.2 Determinants of Instrument Choice

For basins in which the gains from management exceed the costs of collective action, the question becomes how to manage. The choice of policy instrument will depend on several political and economic factors. Major evaluation criteria discussed in the literature include the relative cost-effectiveness of different policies, the distribution of benefits and costs among users, and the minimization of risk associated with missing the policy target in the face of uncertainty (Baumol and Oates, 1988). The optimal policy instrument for a given basin will depend on the subjective weight placed on each dimension and the political feasibility of implementing a given strategy.

Hypothesis 4 *Interests of governing board members may influence policy instrument choice.*

The cost-effectiveness advantage of incentive-based policies depends on the heterogeneity among regulated firms (Goulder and Parry, 2008). In the context of groundwater, we may expect to see markets emerge in places where variation in demand for groundwater is greatest. Heterogeneity in groundwater demand may stem from differences across users in the marginal value product of groundwater and the marginal cost to extract. Marginal value product will vary with the crops grown in the region and the presence or absence of urban water consumers while the marginal costs to extract will vary with the depth to groundwater. We can proxy for local heterogeneity in groundwater demand by considering the variation in crops grown in a given region.

Hypothesis 5 *Trading is more likely to occur where greater heterogeneity exists in demand for groundwater.*

4 Data

The early implementation of SGMA provides an opportunity to compile data that characterize trends in groundwater management, including where, how, and why groundwater management is occurring in the state. To characterize groundwater management under SGMA, we collected publicly available data on basins, GSAs, and their GSPs from DWR. First, we created a GSP-level dataset on policy instrument choice, including all demand-side programs under consideration and which GSAs are involved in which GSP, by reviewing all 107 groundwater sustainability plans that had been submitted to DWR by May 2022.[6] Second, we assembled data on the control of governing board seats by inspecting GSA formation documents and websites. Third, we link these to a basin-level dataset on priority status, including whether or not each basin is critically overdrafted, and information on crop acreages. These data were collected for all 343 groundwater agencies and all 107 groundwater plans that were submitted to DWR. The 94 medium- and high-priority basins, on which 236 GSAs formed to collectively write and submit 102 GSPs, were the only areas mandated to do so under the law. An additional 5 low and very low priority basins voluntarily submitted plans which were also included in our analysis.

Table 1 provides a descriptive overview of the variables collected, including the unit, number of observations, interpretation, and source. The data comprise a cross-sectional snapshot of how SGMA is unfolding.

GSPs include lists of management actions that the GSA is considering to achieve sustainability. These vary a great deal in terms of specificity and certainty. Though the majority of management actions listed in GSPs are supply augmentation and conservation projects conducted by GSAs themselves, we focus exclusively on management actions that alter the pumping incentives of groundwater end users. We characterized these management strategies in each GSP by recording the intentions of GSAs to set allocations or pumping restrictions, allow trade, set taxes or fees, or provide incentives for conservation and efficiency improvements. The presence or absence of a given strategy was characterized as "Yes," "No," or "Maybe" to reflect the natural uncertainty at this early stage of SGMA development. If plans stated that a given strategy would be developed or implemented, regardless of the degree of detail described, we marked them as a "Yes." Plans were given a "Maybe" designation with language such as "we may adopt" or "we may consider implementing" a certain strategy.[7] Even in GSPs with highly certain language,

[6]In cases where smaller GSAs joined to form a larger GSA (e.g. the Northern Delta GSA), we count only the smaller, individual GSAs.

[7]Levels of both specificity and certainty vary substantially between GSPs; where one plan may include a throwaway line about potentially considering a pumping charge, another may set out a multi-page plan for

Table 1: Variables Collected

Data	Interpretation	Primary Source
GSA Level (343 obs, 236 signatory to a "High" or "Medium" Priority GSP)		
Board Seats	List of districts, cities, etc. with board representation	GSA Formation Documents, GSA websites
Single Agency	Is GSA a single agency? (As opposed to MOU, JPA)	From Board Seats
GSP Level (107 obs, 102 "High" or "Medium" Priority)		
GSA Participants	List of GSAs included in GSP	GSP Submissions
Allocations	Does GSP include making an "allocation"? Y/M/N	GSP Submissions
Trading	Does GSP allow trading of allocations? Y/M/N	GSP Submissions
Taxes or Fees	Does GSP impose taxes or fees? Y/M/N	GSP Submissions
Tax Base	What is the tax based on? Acreage, extraction, not specified	GSP Submissions
Rate Structure	How is the tax structured? Tiered, flat, not specified	GSP Submissions
Pumping Restrictions	Does the GSP impose other restrictions on pumping? Y/M/N	GSP Submissions
Restriction Description	Open field describing pumping restrictions	GSP Submissions
Efficiency Incentives	Does GSP offer incentives for conservation/efficiency? Y/M/N	GSP Submissions
Incentive Description	Open field describing conservation/efficiency incentives	GSP Submissions
Crop Acreages	Acres harvested in specific crops in 2014	Land IQ
Subbasin Level (515 obs, 94 "High" or "Medium" Priority)		
Priority	DWR-assigned priority for SGMA compliance	DWR
Critical Overdraft	Is basin in critical overdraft?	DWR
Prioritization Data	All data used for prioritization by DWR	DWR

Notes: The table summarizes the variables collected with source information. Gaps in district-level data were filled manually. GSA formation documents and GSP submissions are accessible at https://sgma.water.ca.gov/portal/.

plans are subject to change, especially where litigation prevents immediate action. Despite these drawbacks, management plans in GSPs offer the most complete description of management actions on the table at this nascent stage of SGMA implementation.

Each category of management action that we record is an abstraction that captures many varied management responses. Here, we give further detail about the definitions of each management action variable recorded.

Allocations

Adjudication has long been an available but costly option for California groundwater basins seeking to establish formalized property rights to water. Without undergoing adjudication, California law prevents a clear, simple groundwater entitlement allocation; therefore, policies suggesting allocations often avoid using that word directly or function as allocations only in roundabout ways. For example, it is not uncommon to see a two-tier block rate structure where the first rate is basically free and the second rate is prohibitively expensive. In this way, the initial tier basically constitutes an allocation. Other plans discuss allowing farmers to generate groundwater "credits" by pumping below some expected/allowable level which can be sold to other users. Not all GSPs that discuss allocations specify how the allocations will be made; among those that do, allocations based on either historic pumping or owned acreage are common.

Trading

This variable is only relevant for GSAs making (or at least considering making) allocations and includes any procedure whereby allocation owners can trade their allocations to other groundwater users in cash sales. Trading schemes often come with restrictions, including bans on exporting water outside the basin or volumetric limits. We do not include individual banking and borrowing (trading across time periods rather than across users) in this variable.

Taxes or Fees

New authority to levy taxes on groundwater extraction is a major new power bestowed on GSAs by SGMA. This variable includes new taxes that affect agricultural production decisions on some margin (i.e., it excludes completely flat fees imposed on every property owner). For taxes and fees that specify their tax basis (groundwater extraction, irrigated

a specific groundwater allocation and market development scheme, perhaps even with results from a pilot.

acreage, or acreage), we record this as well. This variable does include the tiered extraction taxes that make up some of the allocation schemes as described earlier. Among the GSPs that specify a tax structure, all plans involve tiered (as opposed to flat) rates. Most plans leave the specific monetary level of the tax to future determination.

Ad hoc Pumping Restrictions

While all of the above can be considered "pumping restrictions" in some sense, we reserve this variable for outright bans on pumping in certain circumstances or geographies. These restrictions generally take the form of conditional restrictions that are triggered in event of a drought declaration, for example. Many GSPs receive a "Maybe" in this category for the inclusion of a vague sentence alluding to the potential need to consider outright pumping restrictions in the event that the remainder of the GSP management actions are insufficient for achieving sustainability. Other examples include geographic pumping bans to prevent specific undesirable outcomes like seawater intrusion or impacts to groundwater-dependent ecosystems.

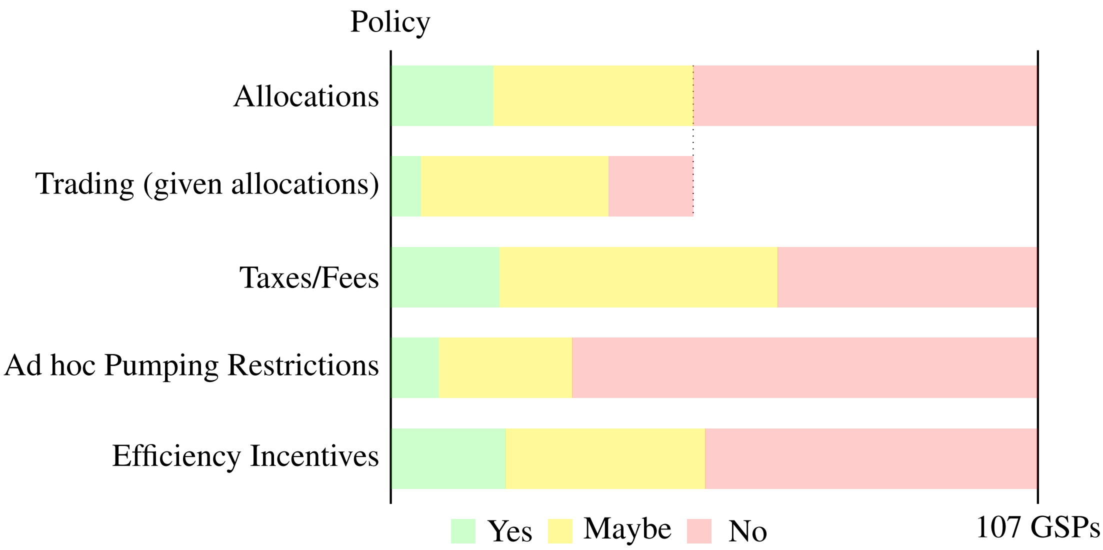
Efficiency Incentives

Of all the variables, this captures the broadest diversity of policies. Examples include payments for fallowing, switching to less water-intensive crops, investments in more water-efficient irrigation infrastructure, and payments for residential rainwater harvesting, lawn removal, or appliance efficiency. Importantly, this variable does not include descriptions of existing water utility efficiency programs (they must be new), programs offering merely education or technological support without direct monetary incentives, or efficiency improvements made only to the infrastructure directly controlled by the agencies forming the GSA, e.g., canal lining.

5 Results

We first document the broad trends of how the GSAs are planning to meet the sustainability requirements of SGMA, with a focus on the demand-side strategies, and then identify patterns and characteristics that predict the proposed strategies.

Figure 2: Breakdown of Proposed Management Actions



Note: The figure displays a summary of proposed demand-side policies. Data were collected manually from 107 Groundwater Sustainability Plans submitted to the Department of Water Resources, available on the online SGMA Portal. Detailed definitions of each variable are provided in Section 4.

5.1 Policy Instrument Choice

A breakdown of the number of plans that suggest a given policy is reported in Figure 2. Our count of reported management strategies reveals both substantial variation in the approaches taken by local agencies and a substantial departure from pre-SGMA management strategies. Notably, 17 plans report the establishment of individual groundwater pumping allocations, with another 33 plans considering setting such allocations. Prior to SGMA, this type of quantification was only achieved through a costly adjudication process. A smaller subset of these plans are developing groundwater markets (5) or considering the development of markets (26) to facilitate trade of these newly defined allocations.

The establishment of taxes or fees on groundwater extraction or land use represents another departure from the previous status quo in which groundwater pumpers faced only the energy costs to extract groundwater from below. Taxes and fees represent one of the most common demand-side management actions proposed by GSAs with 18 GSPs outlining definite plans and another 46 with possible plan to institute a tax, together representing 60% of the plans in our data.

Of the 107 GSPs submitted to DWR, 19 of them exclude mention of any demand-side strategy, and are likely relying exclusively on supply-side strategies to correct overdraft and achieve sustainability. These supply-side strategies include importing additional surface water supplies for in-lieu groundwater recharge, artificial groundwater recharge with excess winter flood flows, and recycled water programs. While these programs may help achieve the goal of slowing or stopping groundwater drawdown, they also impose costs on the district that must be recuperated. Rather than aligning the individual and social costs of pumping, these projects drive a larger wedge by socializing the costs of finding additional water sources when groundwater is over-extracted.

Figures 3 and 4 show the spatial distribution of (1) allocations and trading and (2) taxes and fees, respectively, with definite and potential proposals shown separately. A look at the spatial spread reveals a concentration of these policies in the Tulare Lake region of the southern Central Valley where the majority of critically overdrafted basins reside.

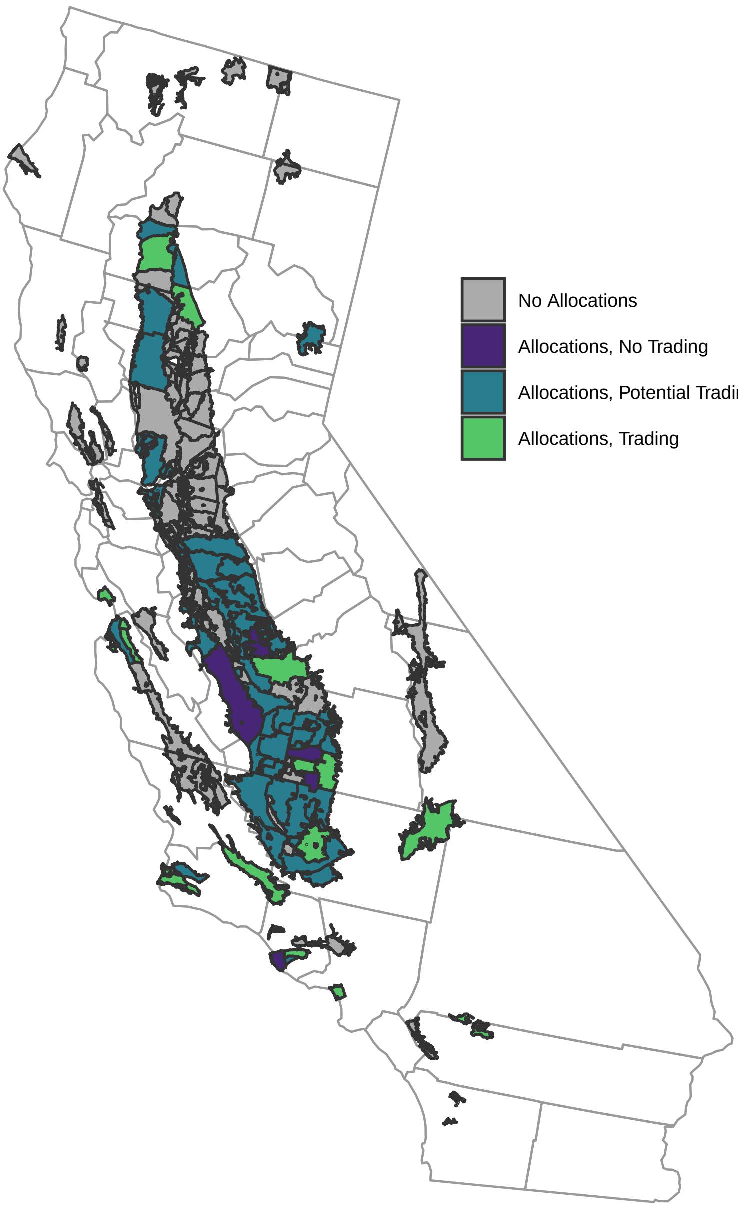
5.2 Determinants of Collective Action and Instrument Choice

We next explore how collective action and policy instrument choice correlate with different features of the localities in which they emerge to shed light on the hypotheses laid out in Section 3. Table 2 reports these associations, restricting the sample to only GSPs that report definite plans to proceed with a given management strategy.

Hypothesis 1 (Gains from Management). We expect that collective action is more likely to occur where the gains from management are greatest. Not surprisingly, the presence of each demand management strategy (allocations, taxes, pumping restrictions, or efficiency incentives) being implemented with confidence is positively correlated with a basin being designated as critically overdrafted.

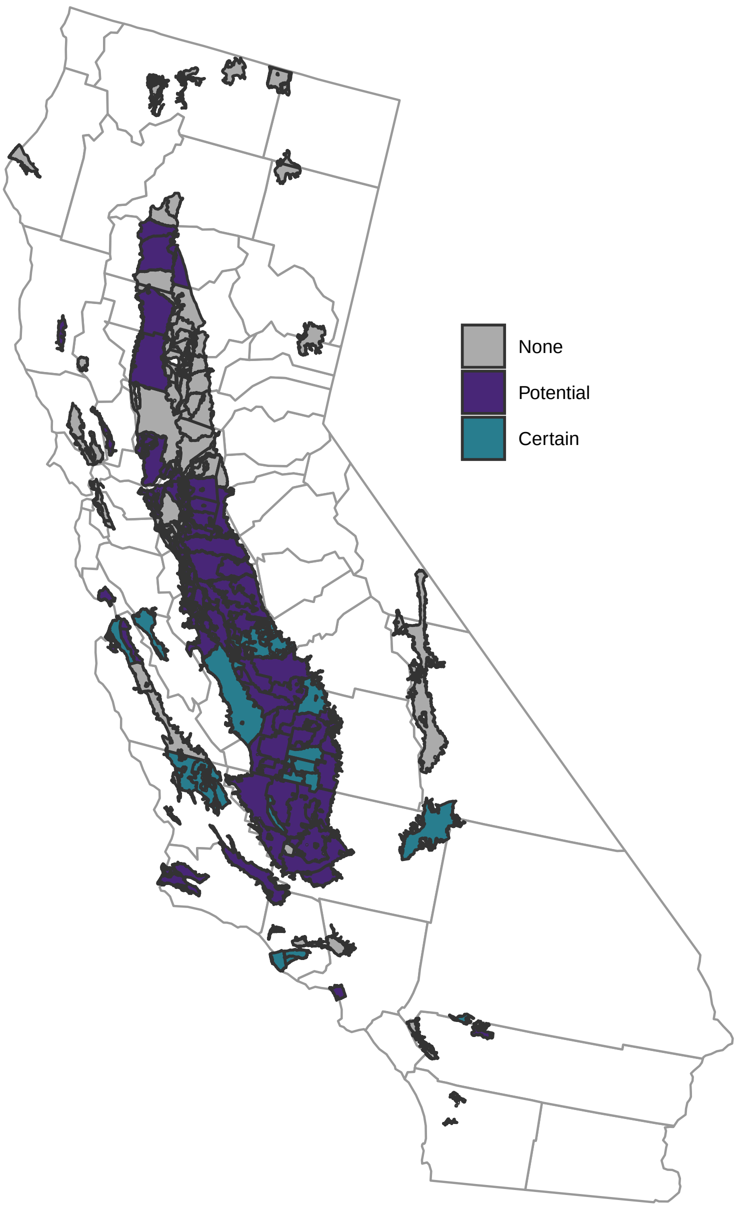
Hypothesis 2 (Number of Bargaining Parties). The next two variables – the number of GSAs coordinating on one GSP and the number of board seats governing GSAs involved in the GSP – proxy for the number of bargaining actors. We anticipated that a larger number of players reduces the likelihood of collective action. However, column (6) reveals a positive correlation between these proxies and the likelihood of any demand management action being proposed. Comparing across columns, plans with a larger number of coordinating GSAs are more likely to propose pumping restrictions and efficiency incentives than allocations, trading, or taxes. However, these correlations are fairly weak and have inconsistent signs across types of policy instruments, so there is not strong evidence to support nor to oppose the hypothesis.

Figure 3: Allocation and Trading Programs



Note: The map shows the spatial distribution of Groundwater Sustainability Plans that proposed allocations and trading. Both certain and potential allocations are included in this map. Data were collected manually from Groundwater Sustainability Plans submitted to the Department of Water Resources, available on the online SGMA Portal.

Figure 4: Proposed Fees



Note: The map shows the spatial distribution of Groundwater Sustainability Plans that include proposals for fees on extraction, irrigated acreage, or some other measure of water intensity. Data were collected manually from Groundwater Sustainability Plans submitted to the Department of Water Resources, available on the online SGMA Portal.

Hypothesis 3 (Heterogeneity of Bargaining Parties). To shed light on this hypothesis, we construct a Herfindahl–Hirschman Index (HHI) of the concentration of GSA board seats held by different interest types and show the correlation between this and policy outcomes in row 4. This variable captures the concentration of voting power within a certain type of groundwater user. Large values of the index suggest a high concentration of interests and less diversity. Likewise, small values of the HHI implies more diversity of interests represented on the governing board. Overall, we find a negative correlation between the board seat HHI and the presence of any demand management, meaning that greater diversity of bargaining parties correlates with an increased likelihood of collective action.

Hypothesis 4 (Balance of Power). The next set of attributes, which describe the representation on the board, proxy for whose interests are dominating. Many local water and land use agencies elected to partner with other organizations and form multi-agency GSAs. GSAs pursuing this route formed boards, with substantial leeway to design board size and representation. Some GSAs granted board seats to non-agency partners, like water companies, private well stakeholders, or environmental organizations. The majority of GSA board seats are held by special districts and local water agencies. Special districts, including reclamation, water, and irrigation districts, are local government entities created under state law to administer specific public services. An irrigation district, for instance, maintains irrigation canals and distributes surface water. We largely anticipate that special districts are aligned with the incentives and priorities of farmers and agribusiness in their jurisdictions.

Cities and counties are also common board seat holders in collaborative GSAs that are motivated to maintain groundwater supplies for community water systems. Counties have an extra role under SGMA implementation to fill in as the GSA representative for any basin areas left unmanaged by the formation of other GSAs.

A look at the share of seats held by different agency representatives in Table 2 shows that GSPs where the governing boards feature a higher share of seats held by special districts are more likely to propose allocations and taxes and less likely to impose pumping restrictions and efficiency incentive programs. The opposite is true for GSPs with a greater fraction of seats held by cities and counties. These results are suggestive of the hypothesis that unobserved interests of governing parties plays a role in policy instrument choice.

Hypothesis 5 (Heterogeneity of Groundwater Demand). The final variable is meant to capture the heterogeneity in groundwater demand across the GSP-managed area. We construct a Herfindahl–Hirschman Index (HHI) of the concentration of planted acreage among California's top 12 crops in each basin since crop type is a major determinant of water demand. Not all GSPs have values for this since some GSPs cover exclusively non-agricultural land. It is not necessarily clear ex-ante how this should be associated with management decisions. Highly homogenized groundwater uses may make finding agreement easier, but this also limits the potential gains from trade. A look at column (2), shows that conditional on setting allocations, trading programs are negatively correlated with a higher HHI of crop types. A higher HHI implies more concentration and less heterogeneity in groundwater demand. Contrary to hypothesis 5, this proxy suggests that heterogeneity in demand is correlated with a decreased likelihood of allowing trade of allocations.

Table 3 presents the same set of correlations but this time inclusive of potential plans to implement a given policy. Results are consistent between these two samples in terms of both direction and magnitude when considering prioritization of the basin and the share of seats held by different entities. Differences emerge when considering associations between management policies and the number of GSAs or number of board seats.

Table 2: Correlation Coefficients Between Policy Choice and GSP Attributes (“Yes” Only)

	(1) Allocations	(2) Trading*	(3) Taxes or Fees	(4) Pumping Restrictions	(5) Efficiency Incentives	(6) Any
GSP in Critically Overdrafted Subbasin	0.331	0.323	0.406	0.208	0.155	0.323
	(0.008)	(0.018)	(0.008)	(0.009)	(0.009)	(0.009)
Number of GSAs in GSP	-0.071	-0.033	-0.107	0.035	0.131	0.03
	(0.009)	(0.02)	(0.009)	(0.01)	(0.009)	(0.01)
Number of Seats in GSAs in GSP	0.036	-0.219	-0.172	-0.067	0.24	0.133
	(0.01)	(0.019)	(0.009)	(0.009)	(0.009)	(0.009)
HHI of GSA Board Seats by Category	-0.112	0.165	0.095	0.026	-0.224	-0.117
	(0.009)	(0.02)	(0.009)	(0.01)	(0.009)	(0.009)
Share of Seats Held by Special Districts	0.01	0.173	0.121	-0.013	-0.123	-0.077
	(0.01)	(0.02)	(0.009)	(0.01)	(0.009)	(0.009)
Share of Seats Held by Cities and Counties	-0.106	-0.064	-0.089	0.107	0.009	-0.006
	(0.009)	(0.02)	(0.009)	(0.009)	(0.01)	(0.01)
HHI of Area Harvested Among Top 12 CA Crops	-0.185	-0.24	-0.153	-0.117	-0.23	-0.29
	(0.009)	(0.019)	(0.009)	(0.009)	(0.009)	(0.009)

Notes: The table presents correlation coefficients between management actions and GSP attributes. We focus here on management plans that are considered definite and exclude management plans that are simply under consideration (“Yes” only). Standard errors are reported in parentheses. For counting seats, single-agency GSAs are considered to have a single seat controlled by the forming agency. *When considering how trading correlates with GSP attributes, we restrict the sample set to only plans that are setting allocations.

Table 3: Correlation Coefficients Between Policy Choice and GSP Attributes ("Yes" and "Maybe")

	(1) Allocations	(2) Trading*	(3) Taxes or Fees	(4) Pumping Restrictions	(5) Efficiency Incentives	(6) Any
GSP in Critically Overdrafted Subbasin	0.229	0.257	0.581	0.17	0.107	0.273
	(0.009)	(0.019)	(0.006)	(0.009)	(0.009)	(0.009)
Number of GSAs in GSP	-0.095	0.321	-0.013	-0.07	0.092	-0.015
	(0.009)	(0.018)	(0.01)	(0.009)	(0.009)	(0.01)
Number of Seats in GSAs in GSP	0.074	0.142	0.042	-0.048	0.079	-0.055
	(0.009)	(0.02)	(0.01)	(0.01)	(0.009)	(0.009)
HHI of GSA Board Seats by Category	-0.085	0.223	0.138	0.033	0.024	0.081
	(0.009)	(0.019)	(0.009)	(0.01)	(0.01)	(0.009)
Share of Seats Held by Special Districts	0.107	0.373	0.205	-0.048	0.178	0.092
	(0.009)	(0.018)	(0.009)	(0.01)	(0.009)	(0.009)
Share of Seats Held by Cities and Counties	-0.137	-0.178	-0.169	0.046	-0.233	-0.04
	(0.009)	(0.02)	(0.009)	(0.01)	(0.009)	(0.01)
HHI of Area Harvested Among Top 12 CA Crops	-0.231	-0.301	-0.376	-0.039	-0.057	-0.175
	(0.009)	(0.019)	(0.008)	(0.01)	(0.009)	(0.009)

Notes: The table presents correlation coefficients between management actions and GSP attributes. Here we consider management plans that are both definite and potential ("Yes" and "Maybe"). Standard errors are reported in parentheses. For counting seats, single-agency GSAs are considered to have a single seat controlled by the forming agency. *When considering how trading correlates with GSP attributes, we restrict the sample set to only plans that are setting allocations.

6 Concluding Remarks

In many ways, the Sustainable Groundwater Management Act builds naturally on historical institutional developments that have occurred in the use and management of both surface water and groundwater over time. Prior appropriation laws, which emerged shortly after westward expansion began, enabled landowners without direct access to river water to construct ditches for diversions, which could be shared among nearby landowners. The high costs of constructing water storage and delivery infrastructure led to the development of mutual water companies and irrigation districts to solve the collective action problem of making necessary infrastructure investments (Libecap, 2011; Hanemann, 2014; Leonard and Libecap, 2019).

By contrast, groundwater extraction does not require expensive capital for storage and distribution, meaning groundwater use required far less neighborly cooperation to develop. U.S. irrigation in the 20th century remained fairly flat over the first four decades of the century, with slow gains in irrigated acreage driven mostly by the formation of new surface water districts. After 1940, technological innovations such as center-pivot irrigation led to an explosion in irrigated acreage supplied by groundwater pumping, managed by individuals and operating outside the auspices of irrigation districts or cooperatives (Edwards and Smith, 2018). As groundwater pumping advanced and losses from open-access management became apparent, collective action (or costly adjudication) began to emerge, although collective action over groundwater has remained difficult in many settings.

In this paper, we studied the early and ongoing implementation of California's Sustainable Groundwater Management Act through a political economy lens. While the regulation is still in its infancy, proposed policies shed light on how agencies are tackling sustainability mandates, revealing which governance and basin characteristics are correlated with various policy outcomes. We compiled a novel dataset that documents the proposed strategies in 107 management plans and used it to test hypotheses about collective action and policy instrument choice. Consistent with expectations, we found collective action to be more likely in basins characterized by a greater degree of overdraft, likely indicative of greater returns from management. We found evidence to suggest that homogeneity in groundwater users and board representatives was associated with decreased likelihood of demand management. We found no evidence of trading schemes being more likely to occur where greater heterogeneity of demand exists, despite potential for greater cost-effectiveness relative to other instruments.

Open-access issues around groundwater will become even more critical to resolve as climate change causes higher temperatures, alters the frequency and severity of droughts, and shifts the precipitation regime. Our assessment of California's Sustainable Groundwater Management Act has shown that efforts by a centralized government to reduce transaction costs over bargaining can drive local management. In other groundwater-stressed regions of the world characterized by many competing actors and large transaction costs, policy changes that reduce information asymmetries and force negotiation may be fruitful avenues for collective action in the face of climate change.

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