Agricultural Water Trading Restrictions and Drought Resilience

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ABSTRACT *Policies that seek to reduce groundwater open-access externalities may be in conflict with the facilitation of water trading during droughts. Using panel data on cropland values, we examine this interaction in the context of groundwater export restrictions. We find that land subject to restrictions experienced a relative decline of 34% ($2,057/acre, roughly half of foregone potential water sales revenue) during the drought immediately following implementation of the policies. During a later, more severe drought, there is no difference in value. Our empirical approach also provides novel estimates of the value of changes in groundwater stock.* (JEL Q15, Q18)

1. Introduction

For more than three decades, economic research has focused on the benefits of relaxing institutional constraints on water trading so that water can be allocated to its most valuable uses (e.g., Howe, Schurmeier, and Shaw 1986). Apart from the physical limitations associated with transporting large quantities of water between sellers and buyers, numerous political and institutional obstacles prevent efficient water markets from taking hold. For one, it can be challenging to implement mutually beneficial water markets given the need to take into account costs and benefits across a diverse array of stakeholders, including farmers, urban dwellers, and environmental groups. Third-party effects, where parties external to a given transaction are indirectly harmed, represent a specific challenge that must often be taken into account when designing water markets and other allocation frameworks (Heaney et al. 2006).[1] For irrigated agriculture, these externalities are particularly salient and typically involve longstanding institutions that may inhibit the establishment of competitive markets or other efficiency-enhancing reallocation mechanisms (Hanak 2005; Bourgeon, Easter, and Smith 2008; Regnacq, Dinar, and Hanak 2016).

In this study, we investigate the extent to which local groundwater export restrictions are associated with differential trends in land values and, in turn, the marginal valuation of groundwater resources. Implemented in California during the 1990s, following long droughts when state-sponsored drought water banks facilitated short-term water transfers, the export restrictions essentially blocked the dual use of groundwater for irrigation and surface water for outside-county sale (or "export"), a practice known as "groundwater substitution." By allowing certain farmers to sell water without cutting back on production, groundwater substitution provided an additional revenue stream for farmers with access to both surface water and groundwater. Of

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[1] Examples of third-party effects include groundwater depletion for other users in the basin if the sellers of surface water pump additional groundwater to continue farming, or the loss of farm-related jobs in the area of origin of water sales if water sellers fallow their land and reduce agricultural production.

Appendix materials are freely available at http://le.uwpress.org and via the links in the electronic version of this article.

primary concern to the local policy makers who chose to establish export restrictions—policies that were differentially adopted at the county level—was the protection of nontrading parties from the external costs, or third-party effects, of groundwater substitution (Hanak 2003). We use a novel panel data set of microlevel land values to study if export restriction status creates a meaningful distinction in terms of how land values evolved during subsequent drought periods, when the opportunity to sell surface water would be greatest. In addition to estimating these differential trends, we also analyze differences in how groundwater is capitalized into cropland values. To further study the distributional consequences of the export restrictions, we decompose our results based on irrigation district membership, which largely determines surface water access and, hence, the farmers to whom the restrictions could be most costly.

Empirical research on the impact of groundwater management has useful policy implications, as it is very difficult to predict a priori how groundwater management policies will affect users or social welfare in general. With a simplified model of groundwater use that includes fixed recharge rates and irrigated acreage, Gisser and Sanchez (1980) find that welfare gains to solving the groundwater open-access problem may not be sufficient to justify a policy intervention. Koundouri (2004a), however, reviews a number of empirical studies that show how, under more realistic assumptions about aquifer structure and irrigator behavior, there are likely to be larger efficiency gains for policies that achieve optimal groundwater management. Although it is theoretically possible to price and allocate groundwater at a socially optimal level (Koundouri 2004b), in practice various tools are used to manage groundwater that are subject to both imperfect information and political considerations. Despite these challenges, many groundwater management policies, although not first best, can lead to improved outcomes (Kuwayama, Young, and Brozovic 2013).

In the case of groundwater export restrictions, the impact on users is uncertain. If groundwater was being optimally managed prior to the policies being implemented, the restrictions would harm users. The loss of use rights may be further affected by loss of option value for current nonusers, as described by Petrie and Taylor (2007). While, in theory, markets allow water to go to its most efficient use, if open access to groundwater in the presence of water markets is not optimal, restrictions to trade could have long-term benefits for those who have access to groundwater by allowing aquifers to recharge. This inherent ambiguity in groundwater trade restrictions is reflected in existing empirical work. Ifft, Bigelow, and Savage (2018) consider the effects of well development restrictions in Nebraska and find that the costs of these policies are largely borne by farmers in regions heavily dependent on irrigation and during high commodity price years. Edwards (2016) shows how areas in Kansas with relatively higher hydraulic conductivity (and lower aquifer recharge) benefit disproportionately from the establishment of groundwater management districts. Smith et al. (2017), focusing on Colorado, also find that a groundwater pumping tax led to a significant reduction in groundwater use. Overall, however, due primarily to data limitations, the empirical literature on the effects of changes in groundwater management institutions remains relatively scant, particularly as it pertains to distributional effects across different groundwater users.

The present study makes several contributions to the existing literature on the economic effects of agricultural groundwater use. First, to our knowledge, our paper is the first to explicitly consider how agricultural land markets have evolved in the presence of local groundwater export restrictions. Although a few studies have considered the direct static effect of the implementation of groundwater management policy changes on land values (e.g., Ifft, Bigelow, and Savage 2018; Edwards 2016), a separate, related question pertains to how farmland values evolve over time with a given policy framework in place. Given that groundwater is a dynamic resource, the effects of groundwater policy would not be expected to be constant over time. Hence, we analyze the degree to which, once implemented, the export policies coincided with divergent short- and longer-run trends in land values based on prevailing water market (i.e., drought) conditions. Second, our study considers how the effects of groundwater on agricultural land values differ based on flexibility of use (as determined by export restrictions) and access to multiple water sources (as determined by irrigation district membership). While previous studies have shown that a more diversified water portfolio leads to higher land values (e.g., Mukherjee and Schwabe 2015), no existing studies acknowledge how this flexibility may influence the perception of the value of groundwater by different groups of farmers, which has implications for the distributional consequences and feasibility of groundwater policy. Lastly, there has been a growing recognition within the literature to move beyond relatively simple cross-sectional comparisons of depth to groundwater when considering its importance in an agricultural setting. We make progress in this regard by utilizing a panel data set that allows us to focus on how export restrictions alter the relationship between groundwater stocks, water table variability, and land values.

Overall, our results suggest that, in the immediate aftermath of when the local groundwater ordinances were imposed, land values in restricted counties experienced a substantial decline of 34% ($2,057/acre, roughly half of the foregone potential water sales revenue) relative to land in unrestricted counties during the initial postpolicy active water trading period. However, several years later, during a more severe drought, we find that this discrepancy in land values is no longer present. Furthermore, we use a novel method for linking groundwater and land value data to produce evidence that groundwater stocks are capitalized into land values. Our results provide suggestive evidence that reductions in groundwater stock may be more costly for farmers located outside of irrigation district boundaries, where access to surface water is relatively rare.

2. Study Area and Institutional Context

The study area for our analysis is California's Sacramento Valley, which is located in the northern half of the larger Central Valley. Including 10 counties (Figure 1a) and a number of irrigation districts supplied by federal and state water providers (Figure 1b), the Sacramento Valley covers an area running from Shasta Lake in the north to the city of Sacramento and the Sacramento–San Joaquin Delta (henceforth referred to as "the Delta") in the south.[2] The primary crops grown in the Sacramento Valley include rice, alfalfa, winter wheat, and an assortment of specialty crops.

A major factor that distinguishes the Sacramento Valley from the rest of California's agricultural land base to the south is its relative water abundance. A large share of the surface water used for irrigation in the southern portion of the state originates from snowmelt in the Sierra Nevada Mountains that collects in the Sacramento Valley. The region is also relatively rich in groundwater, which is a primary supply for domestic users as well as many farms. The federal Central Valley Project (CVP) and the California-run State Water Project (SWP), along with several large autonomous surface water projects, deliver surface water to irrigation districts in the Central Valley. In drought years, the conveyance infrastructure these projects provide is also used to transfer water from sellers in the Sacramento Valley to buyers in the south.

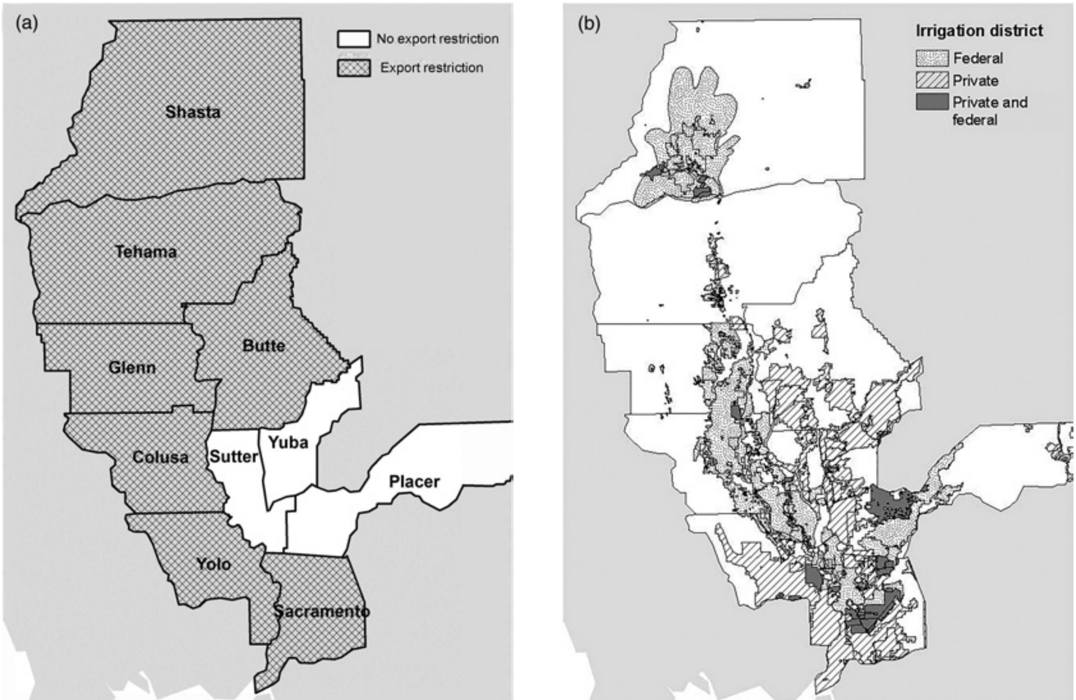
Surface Water "Haves" and "Have-Nots"

In California, as in much of the western United States, public agencies or irrigation districts, and some municipalities, hold most of the surface water rights (Libecap 2011; Griffin 2012). As Smith (1989, 448) notes, about 50% of irrigated acreage in the western United States is serviced by either a private mutual company or public water district. For California, in 2013 about 66% of irrigated acreage used off-farm surface water for some portion of total applied irrigation water (USDA-NASS 2013).[3] This fact makes irrigation

[2] Sample counties in the Sacramento Valley are Shasta, Tehama, Glenn, Butte, Colusa, Sutter, Yuba, Placer, Yolo, and Sacramento.

[3] The USDA Farm and Ranch Irrigation Survey (USDA-NASS 2013) identifies 7.54 million irrigated acres in California, of which 1.45 million acres are irrigated exclusively with groundwater. Of the remaining 6.10 million

Figure 1
Sacramento Valley Study Area: (a) Export Restriction Counties; (b) Irrigation Districts



districts key players in managing agricultural water and facilitating water transfers during droughts. In contrast to most groundwater basins in southern California, groundwater rights have not been adjudicated throughout most of the Central Valley, and pumping is generally permitted for all users overlying the aquifer (Attwater and Markle 1987).

Water districts are pseudogovernmental organizations that deliver irrigation and related services within defined geographical boundaries. In California, districts deliver surface water to most farmers (McCann and Zilberman 2000; CSLGC 2010).[4] As it pertains to our analysis, a key feature of district farmers is their access to water conveyance structures, in the form of linked reservoirs, canals, and pumps, which enable member farmers to participate in out-of-watershed water transfers.[5] The locations of all districts in our study area are shown in Figure 1b.

Despite its relative water abundance compared to other parts of California, the Sacramento Valley is characterized by an uneven distribution of water rights. District farmers often use groundwater to supplement their surface water supplies, particularly in drought

acres, about 4.01 million acres are irrigated with off-farm surface water.

[4] Special districts first arose in California to meet the water needs of farmers. Faced with an inconsistent water supply and unstable prices, farmers in Stanislaus County organized the Turlock Irrigation District under the Wright Act of 1887. The Wright Act allowed landowners to form new public entities to deliver irrigation water, and to finance their activities with water rates and bond sales. As California's first special district, the Turlock Irrigation District made it possible for local farmers to intensify and diversify their crops. Today, there are hundreds of special water districts in California, with a great diversity of purposes, governance structures, and financing mechanisms. Irrigation districts can be semigovernmental or independent organizations. We refer to these myriad organizational forms simply as "districts" in our analysis. See CSLGC (2010) for a brief history of the development of special districts.

[5] All water transfers conducted using surface water associated with district-managed rights are subject to approval by the district in which the transferring farm resides, as the district is responsible for ensuring that other members will not be harmed by the transfer.

years when supplies are curtailed, but farmers not affiliated with water districts, and therefore without access to CVP or SWP deliveries, also constitute a significant portion of the farming population. These "nondistrict" farmers rely on groundwater as the primary source of irrigation water.[6] As Hanak (2003) has recorded in detail, local attitudes toward groundwater use, particularly during times of drought, have been polarized along the divide between surface water "haves" and "have-nots."

California's Water Market and Groundwater Export Restrictions

California's experience with water marketing began with the successive drought years of the early 1990s, when the state government facilitated reallocation of water from senior water right holders with lower valued uses such as field crops (e.g., rice) and pasture, to higher valued uses such as environmental flows or urban consumption, via drought water banks (DWBs) (CDWR-SWRCB 2015). These DWBs were significant policy innovations in that they were the first large-scale temporary water markets set up and run by a state government. In subsequent years, water marketing activity continued. Irrigation districts play a large role in facilitating water transactions. Specifically, districts with senior water rights may find that their water supply is not curtailed in a drought year, giving member farmers an opportunity to sell their surface water allocation.[7] In a temporary, or short-term, market, farmers can typically sell their surface water allocation by (1) fallowing for a season or (2) continuing agricultural production by substituting groundwater for the foregone surface water allocation (CDWR-SWRCB 2015). Such short-term water transfers are an important tool used by farmers to cope with droughts and constitute 25% to 75% of all water volume traded in a year (Hanak and Stryjewski 2012).[8] Although fallowing and groundwater substitution are two of the most common forms of surface water transfer, other possible, though rarely used, strategies include changes in crop choice, water conservation, and direct groundwater sales (CDWR-SWRCB 2015).

While California has a "no-injury" clause that is intended to protect third parties from unmitigated harm associated with surface water withdrawals, groundwater is treated as a common property resource (Hanak 2005). The initial DWBs of the early 1990s relied on groundwater substitution to facilitate transfers and resulted in lower groundwater levels in some areas (Hanak 2003; CDWR-SWRCB 2015). This fueled local resistance against water sales, particularly from the nonsellers, which included groundwater-dependent farmers and residents (Thomas 2001; Hanak 2003).

In response, by the late 1990s 7 of the 10 counties in the Sacramento Valley had imposed groundwater export and substitution restrictions. As Hanak (2003) documents, these ordinances varied somewhat but generally required farmers interested in groundwater substitution for out-of-county transfers to undergo an environmental review and obtain a trade permit from their respective county government.[9] Groundwater export restrictions have been criticized because they may be poor substitutes for a comprehensive groundwater management policy. The restrictions do not explicitly protect against overdraft by local users, nor do they provide a framework for communities to participate in mutually beneficial water sale opportunities. Hanak (2003) and Hanak and Strykewski (2012) note the

[6] For example, in Butte County, rice farmers in three irrigation districts in the southern part of the county hold senior water rights from the SWP, whereas orchard growers in the northern part of the county rely exclusively on groundwater.

[7] Legally, some of these agencies hold long-term contract-entitlements rather than rights to surface water. These entitlements, governed by California's original Gold Rush era water law "first in time, first in right," are owned by the state and allocated on the basis of beneficial use and priority of initial date of appropriation.

[8] As Brewer et al. (2008) show, there is substantial variation across states in the share of water transactions accounted for by short-term leases, ranging from 3% to 4% in Nevada and Colorado to 83% in Wyoming. California is at the upper end of this distribution, with short-term contracts making up 63% of water transactions.

[9] Direct groundwater transfers tend to be far less common than transfers through groundwater substitution due to the energy costs associated with groundwater pumping and the fact that water pumped from a well is generally less amenable to being transferred through the conveyance infrastructure set up for surface water deliveries.

relatively small number of postrestriction groundwater-based transfers permitted, which suggests that the export restrictions have acted as a de facto moratorium on groundwater substitution-based transfers, as opposed to a screening mechanism that discourages harmful transfers. A more rigorous follow-up analysis by Hanak (2005) examines how the export restrictions affected water exports, imports, and local (within-county) sales. Findings suggest that the reduction in water exports is partially offset by an increase in local, within-county sales.

3. Empirical Strategy

The primary goal of this analysis is to investigate how the water market segmentation imposed by local groundwater export restrictions influenced the subsequent evolution of land values in the Sacramento Valley, an area that has been a net exporter of water in recent history (Hanak and Stryjewski 2012). Our use of land values to measure the effects of interest is appropriate, since access to water (i.e., district membership and ability to pump groundwater) and export restriction status are tied to farming land in a specific location. Moreover, since land values embody the current and future net returns to both agricultural (e.g., irrigation) and nonagricultural (e.g., water sales) uses, land values are a more appropriate measure compared to alternative metrics such as annual cash rents. Our study's time period is 1999–2009, which spans drought years with substantial volumes of traded water and wet years during which no cross-Delta water sales occurred. Groundwater export restrictions, administered at the county level, were already in place by 1999 (the first year of farmland values data availability), hence our focus on differences in post-export-restriction trends.

To measure changes in land values over time based on export restriction status, we build our model around two major cross-Delta transfer programs that were in place during the 1999–2009 period. The modeling strategy is illustrated in the Table 1, which contains information from the U.S. Bureau of Reclamation (2015) on surface water deliveries from the CVP to areas south of the Delta. Since

Table 1
Surface Water Deliveries South of the Sacramento–San Joaquin Delta

Year	% Deviation from Average CVP Deliveries South of Delta	Corresponding Model Variable
1999	5.66	Base period (w_1)
2000	7.31	Base period (w_1)
2001	–8.20	d_1
2002	–3.73	d_1
2003	10.33	w_2
2004	3.54	w_2
2005	28.10	w_2
2006	20.75	w_2
2007	–8.11	d_2
2008	–25.78	d_2
2009	–21.61	d_2

Note: Data on Central Valley Project (CVP) deliveries are tallied for subprojects located outside of the Sacramento Valley but not including the Klamath basin. The long-run average is calculated from 1975 to 2014 and used as the basis for calculating percentage deviation.

the export restrictions largely functioned as a moratorium on out-of-county transfers, we use CVP deliveries outside of the Sacramento Valley to guide our specification. Specifically, we group together time periods with similar weather conditions and trading activity. During the first four years of our study period, there were two relatively wet years (1999–2000), when deliveries outside of the Sacramento Valley were above their long-run average, and two dry years (2001–2002), with below-average deliveries. The 2001–2002 period is the first time the export restrictions were binding from the perspective of Sacramento Valley farmers with access to surface water and delivery infrastructure (i.e., located in an irrigation district). Similarly, the remainder of the study period is also marked by a wet period (2003–2006) and a drought (2007–2009), with the final two years (2008–2009) being associated with the largest relative surface water curtailments (26% and 22%, respectively) during our study time frame of 1999–2009. To measure how land values changed after the imposition of export restrictions, we estimate a model of the following form:

$$v_{it} = \alpha_i + \delta_1 d_1 + \gamma_1(d_1 \cdot ER_i) + \delta_2 w_2 + \gamma_2(w_2 \cdot ER_i) + \delta_3 d_2 + \gamma_3(d_2 \cdot ER_i) + \varepsilon_{it}. \quad [1]$$

In equation [1], the dependent variable, v_{it}, is the (per-acre) land value of parcel i in time t. The variable d_1 is a binary indicator variable representing the first dry (or drought) period of 2001–2002. Similarly, w_2 and d_2 denote the second wet (2003–2006) and dry (2007–2009) periods, respectively. The coefficients δ_1, δ_2, and δ_3 indicate movements in land values over the study period for land not subject to an export restriction, which are interpreted relative to the omitted baseline wet period (1999–2000). Of primary interest are the differential effects of the drought periods in areas where export restrictions, indicated by the ER_i dummy variable, have been put in place. These differential effects are measured by the interaction variable coefficients γ_1, γ_2, and γ_3.[10]

An important component of our model is the inclusion of parcel-level fixed effects, α_i, which account for time-invariant parcel heterogeneity. Among other things (e.g., soil quality, local climate), the fixed effects account for baseline differences in export restriction status. Since the export restrictions were already in place by the start of our study time frame, α_i also accounts for the historical factors that drove some, but not all, Sacramento Valley counties to adopt the restrictions. These factors are covered by Hanak (2003, 2005) and include dependence of residents on groundwater and the importance of agriculture to the local economy. Last, α_i implicitly controls for irrigation district membership and surface water seniority, the latter being an important aspect of California's dual system of water rights that determines which irrigators have their water supplies curtailed during times of shortage. Since these institutional factors are not readily measurable, the ability to implicitly control for them is a critical aspect of the adopted modeling strategy, as it addresses several possible sources of omitted variable bias that could affect our results.

A secondary aim of this study is to analyze differences in groundwater capitalization, as delineated by export restriction status and irrigation district membership. To account for these differences, we estimate an enhanced version of equation [1], which may be written as follows:

$$v_{it} = \alpha_i + \delta_1 d_1 + \gamma_1(d_1 \cdot ER_i) + \delta_2 w_2 + \gamma_2(w_2 \cdot ER_i) + \delta_3 d_2 + \gamma_3(d_2 \cdot ER_i) + \boldsymbol{\beta}'\mathbf{X}_{it} + \boldsymbol{\theta}'(\mathbf{X}_{it} \cdot ER_i) + \varepsilon_{it}. \quad [2]$$

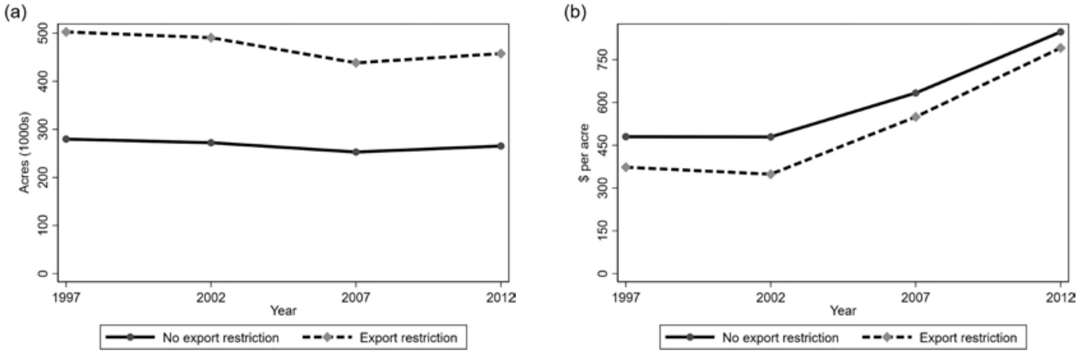
In equation [2], $\mathbf{X}_{it}$ represents a vector of time-varying continuous variables related to aquifer characteristics and water availability, the effects of which are measured by the associated parameter vector $\boldsymbol{\beta}$. Variables included in $\mathbf{X}_{it}$ include depth to groundwater, a measure of water table variability, the share of cropland allocated to orchards and vineyards, and the share of cropland idled. We also interact $\mathbf{X}_{it}$ with ER_i, with the parameter vector $\boldsymbol{\theta}$ measuring how the effects of these variables differ between parcels in restricted and unrestricted counties. Including the interaction effects allows us to gauge whether the export restrictions represent a divide in terms of how farmers perceive the value of groundwater access.

In addition to estimating equation [2] using our full sample of Sacramento Valley land value observations, we also estimate separate models for parcels inside and outside of irrigation district boundaries. Since farmers without irrigation district membership do not generally have access to surface water, we would expect them to be relatively more sensitive to groundwater-related influences. Furthermore, since a motivation for the export restrictions was to protect farmers that were most dependent on groundwater for irrigation, separating district members from nonmembers provides more refined insight into the potential distributional effects of the policies.

As noted above, the lack of available panel data on field-level farmland values prior to the imposition of export restrictions precludes the use of a quasi-experimental approach to measure the direct effect of the export restrictions. Instead, we study the related question of how land values have evolved in the aftermath of the policies being put in place, which sheds light on the extent to which the effects of the export restrictions are dynamic. Since our model has observation-level fixed effects, any causal claims based on the estimation re-

[10] An implied assumption behind this model specification is that the effects of the restrictions are constant across drought years. A more flexible specification would include a full set of year and restriction-year effects. However, this strategy is infeasible in our case given the relatively small sample we have at our disposal (see Section 4).

Figure 2
County Trends by Export Restriction Status, 1997–2012: (a) Total Farmland Acres; (b) Total Crop Sales Revenue per Acre



sults turn on the assumption that there are no differential trends in farmland values related to export restrictions or other variables of interest (or the "parallel trends" assumption). While we cannot disprove that such differential trends exist and do not make strong causal claims, we briefly explore trends in several confounding factors that could potentially influence our results.

Farmland values reflect the underlying productive potential of land, as well as expectations of future yields and prices. Hence, if counties with and without restrictions had divergent production trends, our model may incorrectly attribute these differences to the restrictions. Specifically, counties with lower agricultural income or income growth may have been more likely to take actions that would potentially result in further reductions to farm income. If counties with restrictions were experiencing lower agricultural sector growth, this would be reflected in their land values. In this scenario, a decline in land values in counties with restrictions would not necessarily be due to the restrictions, but broader farm sector trends.

To examine the potential for this type of nonparallel trend to drive our results, we consider county trends in average farmland acres and average crop sales per acre based on export restriction status. As indicated by Figure 2a and b, counties with export restrictions had both a larger land area and greater crop sales revenues. Counties with restrictions had much more land in agriculture (Figure 2a), which may have created more pressure for groundwater management. However, the trends in farmland acres in restricted and nonrestricted counties were moving in the same direction at comparable rates of growth or decline during the entire study period. This suggests that our results will not be attributable to a land-driven decline in the agriculture sector in counties with export restrictions. Crops sales revenues (Figure 2b) also exhibit similar trends and are consistent with the overall movement toward high-value agriculture in California. The one exception is sales between 1997 and 2002, which slightly declined in restricted counties but remained roughly constant in nonrestricted counties. However, after 2002 both sets of counties experienced strong growth in sales coupled with slight declines in farmland acres. The differential in sales per acre did decrease over the study period, which suggests that this ongoing trend toward high-value agriculture would, at most, attenuate our findings on the impacts of an export restriction, to the degree that farmland values reflect the future value of agricultural production.

4. Data

Data Sources and Construction of Variables

The land value data used in this analysis come from the June Area Survey (JAS), a multipurpose annual survey used to inform a variety of U.S. Department of Agriculture (USDA) publications, including the official annual land value estimates. Surveyed areas (or "segments") for the JAS are selected through USDA National Agricultural Statistics Service's (NASS) area-based sampling frame. Sampled segments are approximately one square mile in area and are made up of "tracts," which denote land inside a segment in a common farm operation. Importantly, the JAS sampling procedure consists of a rotating panel, where roughly 20% of sampled segments are rotated out of the survey each year. Data from the survey, including both irrigated and nonirrigated per-acre land value estimates, are collected through interviews with farm operators at the tract level.[11] Although the JAS information is collected at the tract level, for disclosure reasons we are not able to geocode the individual tracts to link them with external data sources (e.g., groundwater depth). Instead, we aggregate the tract-level land values to the segment level using the survey weights in the JAS data set.[12] The segment-level per-acre land value estimates form the dependent variable in our empirical analysis. JAS segments thus represent our unit of analysis. Since the term "segment" is specific to the JAS, we use "parcel" to describe the unit of analysis in what follows. As it relates to equation [1], above, the fixed effects, α_i, capture heterogeneity at the level of JAS segments (parcels).

[11] We note that the surveyed farmers do not necessarily own the land they operate. The JAS is administered to farm operators, irrespective of their ownership of the land. This contrasts with other USDA survey efforts, such as the 2014 Tenure, Ownership, and Transition of Agricultural Land (TOTAL) Survey, which targeted both owners and operators of farmland. Results from the TOTAL Survey indicate that 55% of California's farmland is owner operated (Bigelow, Borchers, and Hubbs 2016).

[12] Prior to aggregating the tract-level land values, we remove any tracts for which the land value estimate is missing or listed as representing the value for "immediate development" purposes. Since the second drought period (2007–2009) coincided with the national housing crisis, removing these observations helps to ensure that our estimates for and in equations [1] and [2] are not being driven by broader macroeconomic trends, although recent research suggests that farmland values were relatively unaffected by the Great Recession (Burns et al. 2018). Prior research using the JAS data also suggests that farmland in California tends to be less influenced by urban proximity, compared to other states (Kuethe, Ifft, and Morehart 2011). To remove data outliers, we also remove tracts that have land values lower than $100/acre or in excess of $50,000/acre.

Although market transactions are often viewed as the preferred data source for hedonic analysis, self-reported land values data can have a number of advantages, and the JAS has been established as a reliable source of farmland values data. While market transaction data can suffer due to market thinness (potentially leading to sample selection concerns as presented by, e.g., Cross, Plantinga, and Stavins [2017] and described by Nickerson and Zhang [2014]) and limited availability of transactions data, the JAS offers a repeated sample of representative per-acre cropland and pasture land values. Previous empirical studies that use the JAS land value data include those by Schlenker, Hanemann, and Fisher (2007), Towe and Tra (2013), Borchers, Ifft, and Kuethe (2014), Ifft, Kuethe, and Morehart (2015), and Ifft, Bigelow, and Savage (2018). Ifft, Bigelow, and Savage (2018) show that hedonic analysis of the impact of irrigation on cropland values using JAS data gives similar estimates as studies using market transactions from Nebraska. Bigelow, Ifft, and Kuethe (2018) likewise find that state-level estimates of average farmland values from transactions data and JAS data in New York are similar after applying survey/acreage weights. In addition, using more aggregate measures, Zakrzewicz, Brorsen, and Briggeman (2012) show that the USDA land values estimates based on the JAS closely approximate or track actual land transaction prices in Oklahoma.

While the JAS values have been used in a variety of contexts, Davis and Quintin (2017) show that self-assessed housing prices may behave differently from sales values during boom and bust periods, which are somewhat analogous to the drought periods we study. Although Ifft, Bigelow, and Savage's (2018) analysis of irrigation water in Nebraska includes several drought years and yields similar estimates to studies using transaction data, we acknowledge that the findings may not generalize to California or other areas. To this end, we note that the effects we estimate may not be identical to those derived from sales data. Specifically, since a farmer's reported market value estimate may represent only one side of a potential farmland exchange, our results could reflect the seller's offer price or willingness to accept, rather than the effects that would manifest in a final transaction price, to the extent that the survey respondents own the land in question and interpret the land value question as reflective of their offer value. Although there are inherent trade-offs between using self-reported values and sales transactions, the JAS data have been demonstrated in many instances to provide reliable farmland value estimates, and the unique panel-based design allows for novel empirical insights (in our case involving postpolicy differential land value trends and a refined interpretation of the value of groundwater stocks) that would be difficult to achieve with sale transactions data. The inherent trade-offs between self-reported land values and market data are an important topic for future research, as varied applied economics research areas rely on both data sets.[13]

Data on Central Valley aquifer characteristics are the second major source of information used in this study. Groundwater depth data are derived from the California Department of Water Resources (CDWR) C2VSim model, which provides annual groundwater head at a number of testing well site locations across the extent of the Central Valley aquifer from 1973 to 2009.[14] Groundwater head is simulated by the CDWR as the height above sea level of the top of the aquifer. To determine the groundwater head of an individual JAS segment i in year t, we calculate the inverse weighted distance average of the nearest five testing wells using the following formula:

$$h_{it} = \frac{\sum_{n(i)=1}^{5} w_{n(i)t} h_{n(i)t}}{\sum_{n(i)=1}^{5} w_{n(i)t}},$$

where $w_{n(i)t}$ is the inverse of the distance between the centroid of JAS segment i and CDWR testing well $n(i)$, and $h_{n(i)t}$ is the head to the water table recorded for neighboring well $n(i)$ in year t.[15] We then use h_{it} to calculate depth to the groundwater table, d_{it}, as $d_{it} = e_i - h_{it}$, where e_i is the elevation of each JAS segment centroid as measured by fine-scale elevation data from NASA's Shuttle Radar Topography Mission.

All models include the depth-to-groundwater variable, which has been used in many prior studies (see Mukherjee and Schwabe 2014 for a review) and has become a standard way of accounting for groundwater accessibility in hedonic models applied to agricultural land. Depth to groundwater serves as a proxy for the energy costs associated with lifting groundwater to the land surface, an implicit measure of the flow value of groundwater for irrigation. However, recent literature has made apparent the difference between the stock and flow values of groundwater resources (Fenichel et al. 2016). In contrast to prior studies that have focused on how cross-sectional variation in depth to groundwater is capitalized into land values, our study is unique in that we have temporal variation in both land values and depth to groundwater. Importantly, the parcel-level fixed effects we are able to include account for aquifer storage potential, a time-invariant land characteristic. As a result, our estimated depth to groundwater effects are derived from parcel-specific deviations from average groundwater depth, which implicitly measures changes in the value of the stock of available groundwater.[16] For interpretation purposes, an increase in depth corresponds

[13] See Banzhaf and Farooque (2013) for an overview of this issue in the context of residential housing markets. More information on the JAS can be found at https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/June_Area/.

[14] Recent published research that uses the C2VSim model data includes that of Medellin-Azuara et al. (2015) and MacEwan et al. (2017). The C2VSim data have a March and October observation for each year. Since the JAS data are collected in June, we restrict our attention to the March data from the C2VSim model in order to avoid having to make any assumptions about the rate of groundwater withdrawal during the irrigation season.

[15] To gauge the sensitivity of our model to alternative weighting procedures, we conduct a robustness check in which the inverse weighting scheme relies on the nearest 10 wells. Results from this alternative model are presented in Section 5. The main conclusions are unaltered when using the alternative weighting procedure.

[16] Technically, this interpretation would also hold for a cross-sectional analysis in which groundwater storage potential (e.g., subsurface porosity and coarseness) and elevation above sea level are spatially homogeneous. However, this is clearly a stylized and unrealistic case. Examination of USGS data on groundwater storage potential indicates the presence of nontrivial cross-sectional variation. For the JAS segments in our study, the average percentage of coarse material in the subsurface (from the surface to 2,300 feet below the surface) is 31%, with a standard deviation of 4% and a range of 20%. Elevation data for the study area, also from USGS, indicate even more variability, with an average

with a reduction in groundwater stock, so we would expect the coefficient estimate for this variable to be negative.

In addition to depth to groundwater, we also account for the variability in groundwater levels recently experienced by farmers. Specifically, we construct a variable representing the coefficient of variation (CV) of depth to groundwater over the previous five years.[17] If farmers are risk averse (e.g., Moschini and Hennessy 2001), we would expect groundwater volatility to have a negative effect on land values, with a larger effect for farmers outside of irrigation districts (i.e., those who are most dependent on groundwater for irrigation).

Two land use variables are included in the specification to represent the shares of cropland idled and devoted to perennial orchard/vineyard production. We include these variables in share form, since the acreage of cropland for a given segment can change over time. As noted above, idling land is an alternative way for farmers to sell their surface water when groundwater substitution is not an option. Since idling-based transfers can occur regardless of whether an export restriction is in place, the cropland idled share variable controls for an important transaction source that is available to all farmers throughout the Sacramento Valley. However, our expectation regarding the sign of the idled land coefficient is ambiguous, as the effect would presumably vary based on land productivity and the rationale behind the idling decision (i.e., some farmers may be forced to idle their land due to low water supplies, while others may idle to reap the financial reward of conducting a water transaction that would offset lost crop revenues). Orchard/vineyard land share is included to account for investments in perennial specialty crop production, which tends to be relatively water intensive and constitutes a long-term farm investment that should be capitalized into land value. Although perennial production represents a durable investment from a grower's standpoint, the USDA-NASS Census of Agriculture[18] reports an 80,000 acre increase in orchard acreage between 1997 and 2012 for our study counties. Given the sizable amount of within-sample variation in this factor, we include it in our model specification.[19]

Since the JAS questionnaire does not ask farmers to report whether they have a well for irrigation, we use well-location data from the Online System for Well Completion Reports (OSCWR) to screen the data set for segments that could not conceivably have had access to a well. OSCWR is maintained by the CDWR and provides data for all wells drilled.[20] The well location data are geocoded to the nearest quarter section. Focusing only on agricultural wells, we assume that a segment is irrigable with groundwater if there is at least one irrigation well within a one square mile buffer of the segment. We also screen the data for

elevation of 127 feet, a standard deviation of 128 feet, and a range of 1,161 feet.

[17] In Section 5 we present the results of several robustness checks in which the variability measure (CV or standard deviation) and the corresponding length of the time lag used in its construction are altered.

[18] See https://quickstats.nass.usda.gov/.

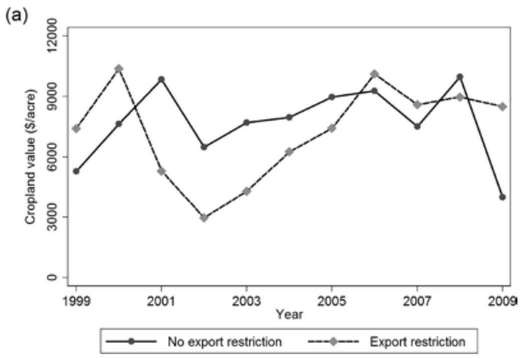
[19] The inclusion of fixed effects in our model mitigates the potential endogeneity of including the orchard/vineyard variable in the econometric specification. Specifically, it could be that higher-valued, more productive land is intrinsically more suitable for perennial crop production. However, identification of the idling and orchard effects relies on the assumption that these inherent factors (e.g., soil productivity or water seniority) are fixed over time. To explore this issue, we also estimate a model in which the orchard/vineyard share variable is omitted and the estimates for the other variables in the specification are virtually unchanged. Results from this alternative specification are available upon request.

[20] OSCWR was developed as a result of 1949 California legislation recognizing that improperly constructed and abandoned water wells can be a source of groundwater contamination and a threat to public health. It required a report of groundwater well completion (i.e., well drilling) to be filed with the state of California. Although theoretically OSCWR contains the universe of all groundwater wells drilled since the 1950s, personal communications of the authors with the CDWR staff revealed that the data are relatively more complete in the northern Central Valley, which is our study area. Due to privacy concerns, CDWR shared with us only the quarter section location of wells.

The OSCWR also provides data on well depth. Although the parcel fixed effects will control for much of the baseline variation in well depth, there have been some new wells that appeared over the 1999–2009 period. While there is good reason to believe that well depth is not exogenously related to land value (e.g., the owners of more valuable land can afford the additional expenses required to sink deeper wells), we note that including well depth as an explanatory variable does not meaningfully affect the other parameter estimates in the model, nor does it produce a significant effect of its own. These supplemental results are available from the authors upon request.

Figure 3

Median Cropland Value Trends, 1999–2009: (a) Export Restriction Status; (b) Irrigation District Membership



extremely deep or shallow groundwater, dropping the upper and lower 1% of the segments based on the depth to groundwater variable. Data on the two main institutions of interest, groundwater export restrictions and irrigation districts, come from Hanak and Stryjewski (2012) and the CDWR and State Water Resources Control Board (CDWR-SWRCB 2015; CDWR 2017), respectively. Names and descriptions for the main variables of interest are provided in Appendix Table A1.

Data Summary

The total number of usable JAS parcels for the purposes of this analysis is 128, yielding 425 segment-year observations. Appendix Table A1 provides summary statistics for the self-reported land value estimates and the other attributes representing physical groundwater characteristics and institutions. The JAS provides survey weights, which essentially serve as expansion factors that are used to generate estimates that are representative of various state-level (in this case, California) agricultural metrics. All summary statistics described in this section are generated using the survey weights.[21]

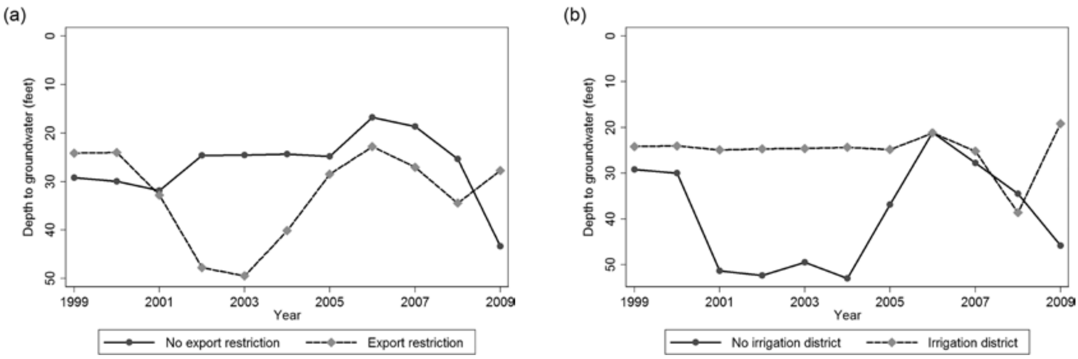
Average cropland values in the Sacramento Valley during our study time frame are $7,339/acre after adjusting for inflation using the consumer price index to 2009 dollars. With a standard deviation of $4,012, land values exhibit considerable variation across both time and space during our study time period. Approximately 58% of the JAS segments are located within irrigation district boundaries, while 75% are located in counties that restrict groundwater-related water exports.[22] Figure 3a plots the median cropland value across our study time period by export restriction status. After an initial peak and decline, land not subject to export restrictions exhibits a steady upward trend in value, exceeding the value of land subject to restrictions from 2001 to 2005, but declining sharply between 2008 and 2009. In contrast, the land value trend for land in export restriction counties declined substantially between 2000 and 2002 before rebounding and plateauing at around $9,000/acre in the latter half of the study period. We further disaggre-

[21] The only significant difference in the weighted and unweighted means from a set of paired *t*-tests, treating the weighted and unweighted sample sizes as equivalent, is for the orchard/vineyard share variable. In addition, apart from the orchard/vineyard share variable, the normalized mean differences (Imbens 2015) in means between the weighted and unweighted samples are all relatively small, with a maximum difference of 0.12 in absolute value. The normalized mean difference for orchard/vineyard share is 0.43 and indicates that the weighted sample contains greater representation of orchards and vineyards compared to the unweighted sample.

[22] We note here that Glenn County's export restriction is relatively more permissive compared to those of other counties in the study area. The estimated marginal effects are robust, in terms of sign and magnitude, to the omission of Glenn County observations in our estimating data set. The smaller sample size results in some loss of precision in the estimates for the subsamples delineated by district membership. Results for the full sample are unaffected in terms of significance. Estimates from this robustness check are available from the authors upon request.

Figure 4

Median Depth to Groundwater Trends, 1999–2009: (a) Export Restriction Status; (b) Irrigation District Membership



gate the trends in land values by surface water access, comparing areas within an irrigation district to areas outside of a district (Figure 3b). While the two trend lines track fairly closely to each other, it is clear that values outside of irrigation district boundaries appear to be more volatile than those within districts, with higher peaks and deeper troughs.

Average depth to groundwater for the sample JAS segments is approximately 47 feet. For much of the study period, groundwater levels were generally lower for land subject to export restrictions (Figure 4a), which partly reflects the rationale behind the ordinances. However, aquifer levels in the unrestricted region declined markedly between 2007 and 2009, a period characterized by significant drought and water trading potential. Depth to groundwater outside of irrigation districts (Figure 4b) has been quite variable, with large declines during droughts followed by recharge in wet years. Farmers without district membership are likely to be more reliant on groundwater for their irrigation needs, using it more heavily during droughts to make up for rainfall shortages. The median aquifer level inside irrigation district boundaries is relatively more stable, with one notable episode of decline and rebound during the drought of 2007–2009.

5. Results

In this section, we present our main estimation results (Table 2), along with a set of robustness checks aimed at measuring the sensitivity of the main results to alternative formulations of the groundwater variables (Appendix Tables A2–A4). All results presented in this section are based on models estimated with an inflation-adjusted and logged dependent variable measured in dollars per acre, parcel-level fixed effects, and JAS survey weights. Standard errors for all model specifications are clustered by county (and district membership status, for the full sample) using the wild *t*-bootstrap method outlined by Cameron, Gelbach, and Miller (2008) to control for the small number of clusters in our study. To better facilitate the presentation of the main results, Table 3 provides the total marginal effects computed for both the restricted and unrestricted segments in both percentage and 2009 dollars terms, using the average baseline value for each respective sample.[23]

Main Results

Column (1) of Table 2 contains results from the full sample of Sacramento Valley JAS segments. Relative to the initial wet period (1999–2000), land values in counties without export restrictions during the initial dry period

[23] Given the logged form of the dependent variable, the marginal effects for the continuous variables are readily interpretable as semielasticities. We convert the effects of the discrete variables into percentage terms using Kennedy's (1981) method. For example, the percentage effect of dry period 1 (d_1) can be written as $100\times[(e^{(\hat{\delta}_1-\sigma^2_{\hat{\delta}_1}/2)}-1]$, where $\hat{\delta}_1$ represents the parameter estimate for dry period 1 and $\sigma_{\hat{\delta}_1}$ is its associated standard error.

Table 2
Fixed Effects Model Estimation Results

	Full Sample (1)	Inside Irrigation District (2)	Outside Irrigation District (3)
Dry period 1 (2001–2002)	0.043 (0.64)	0.106 (0.48)	–0.062 (–3.08)***
Wet period 2 (2003–2006)	0.116 (0.61)	0.281 (0.49)	–0.138 (–0.59)
Dry period 2 (2007–2009)	–0.009 (–0.06)	0.191 –0.880	–0.364 (–3.08)***
ER × Dry period 1 (2001–2002)	–0.461 (–2.14)**	–0.417 (–1.90)*	–0.401 (–0.88)
ER × Wet period 2 (2003–2006)	–0.226 (–0.94)	–0.343 (–0.97)	0.071 (0.54)
ER × Dry period 2 (2007–2009)	0.018 (0.11)	–0.104 (–0.46)	0.269 (0.95)
Depth to groundwater	–0.039 (–3.09)***	–0.037 (–0.15)	–0.015 (–0.67)
ER × Depth to groundwater	–0.023 (–0.40)	0.024 (0.28)	–0.118 (–2.09)**
Depth to groundwater, CV	–0.219 (–0.64)	0.062 (0.49)	–1.669 (–0.67)
ER × Depth to groundwater, CV	0.211 (0.55)	–0.070 (–0.62)	3.448 (2.06)**
Orchard/vineyard cropland share	–0.146 (–0.74)	–0.135 (–0.16)	–0.150 (–0.67)
ER × Orchard/vineyard cropland share	0.296 (1.31)	0.239 (0.71)	0.577 (2.40)**
Idle cropland acreage	0.094 (0.52)	0.203 (0.15)	–0.492 (–0.67)
ER × Idle cropland acreage	–0.143 (–0.41)	0.091 (0.19)	0.312 (0.68)
Number of JAS segments	128	82	46
Number of JAS segment-years	425	270	155
Weighted sample size	83,908	48,392	35,516

Note: The dependent variable is the logged real per-acre land value (in 2009 dollars). All models contain June Area Survey (JAS) segment fixed effects. *t*-Statistics generated by clustering standard errors by county and district membership using the wild *t*-bootstrap approach outlined by Cameron, Gelbach, and Miller (2008) are presented in parentheses. CV, coefficient of variation; ER, export restriction.
*, **, *** Significance at the 10%, 5%, and 1% levels, respectively.

(2001–2002) are not meaningfully affected, which contrasts with a decline of 34% ($2,057 per acre, on average; computed using the combined baseline and interaction effect for dry period 1) in counties that implemented export restrictions. In subsequent periods, namely, the second wet (2003–2006) and dry (2007–2009) periods, land values are not appreciably different than those in the baseline period. Further, the difference in the coefficients for land in counties with and without export restrictions vanishes. Taken together, these results are consistent with the idea that the export restrictions were perceived by farmers to pose short-term opportunity costs that dissipated over time. Alternatively, farmland operators may have become less pessimistic about the impacts of groundwater export restrictions after opportunities to substitute out-of-county water exports with increased local sales were realized (Hanak 2005). Turning to the groundwater variable coefficients, we find that land in counties without restrictions experiences a reduction in value of 3.9% ($233) for each additional foot of reduction in groundwater stock. Groundwater variability (as measured by the CV) has the expected negative sign but is not statistically significant, nor are the idled cropland or orchard/vineyard share variables.

The next two columns in Table 2 disaggregate the results of column (1) by irrigation district membership. Irrigation district members would be expected to be most directly affected by the export restrictions, since member farmers would presumably have greater access to surface water they could potentially export. District members (column 2) in counties without export restrictions do not experience any significant land value appreciation in the initial dry period. However, the effect for land subject to export restrictions amounts to a 36% decrease relative to land not subject to a restriction (not shown in Table 3), though the total marginal effect (i.e., taking into account the baseline dry-period effect, which is positive, and the interaction) is itself not distinguishable from zero. The effects for the second wet and dry periods are insignificant for the entire irrigation district sample. These results support those derived from the

Table 3
Marginal Effects, by Time Period and Export Restriction (ER) Status

	Full Sample % ($/acre) (1)	Inside Irrigation District % ($/acre) (2)	Outside Irrigation District % ($/acre) (3)
Dry period 1 (2001–2002), no ER			–6.07 (–441)***
Wet period 2 (2003–2006), no ER			
Dry period 2 (2007–2009), no ER			–31.00 (–2,252)***
Dry period 1 (2001–2002), ER	–34.20 (–2,057)**		–45.67 (–3,318)*
Wet period 2 (2003–2006), ER			
Dry period 2 (2007–2009), ER			
Depth to groundwater	–3.88 (–233)***		
Depth to groundwater, ER			–13.29 (–965)**

Note: The base period is 1999–2000, which we refer to as wet period 1. Blank cell entries correspond to marginal effect estimates that are not statistically distinguishable from zero at the 10% significance level. The values in parentheses represent the marginal effects translated into 2009 dollars using the average value for each respective sample. For parcels not subject to export restrictions, the percentage effects shown here are translated from the baseline, uninteracted coefficients in Table 2. For parcels subject to export restrictions, the effects are translated from the combined baseline and interaction coefficients. To conserve space, we do not translate the relative effects for restricted parcels (i.e., the interaction coefficients on their own). The marginal effects for groundwater volatility, orchard/vineyard share, and idled cropland share are not statistically distinguishable from zero.
*, **, *** Significance at the 10%, 5%, and 1% levels, respectively.

full sample, indicating that the potential costs imposed upon farmers in irrigation districts through restricting their water sale opportunities dissipated over time. The effects of the groundwater variables have the expected signs but are not statistically significant in the irrigation district subsample. To some extent, this is expected, as many irrigation district members use groundwater as a backstop, as opposed to primary, water source.

Last, column (3) presents the results for lands located outside of irrigation district boundaries, where groundwater dependence should be greatest. Here, we find a small negative effect of 6% ($441) for unrestricted land during the initial dry period, an effect that increases to 46% ($3,318) for land subject to the export restrictions. This suggests that irrigators without access to surface water were still negatively affected by drought in the immediate aftermath of the export restrictions being implemented. However, during the second, more substantial, drought, the results show that land not subject to restrictions suffered a substantial loss of 31% ($2,252), while land subject to the restrictions was not measurably affected. This provides evidence that the restrictions were relatively beneficial to farmers most dependent on groundwater, namely, those who are not members of an irrigation district, which suggests that the policies may have partially addressed the external, third-party impacts of groundwater substitution on irrigators without access to surface water.

Although they are sensitive to model specification (as shown in the next section) and the sample is relatively small, the groundwater variables for district nonmembers suggest an interesting and intuitive pattern. We do not find a significant effect of groundwater stock for farmers outside of districts in counties without export restrictions. The effect, however, is fairly large, at 13% ($965 per foot), for lands in export restriction counties, which makes sense if the restrictions were put in place to protect third-party farmers most dependent on groundwater for irrigation. Put differently, it would be expected that this group of irrigators would be most sensitive to decreases in groundwater stock. The depth to groundwater CV effects indicate that lands not subject to export restrictions are not affected by groundwater variability.[24] In contrast, for farmers in

[24] The relatively large magnitudes of the CV coefficients are due to the fact that the segment-specific within standard deviations of the depth variable pale in magnitude compared to the mean depth values. In other words, a one unit increase in the depth to groundwater CV, which is used to interpret

counties with export restrictions, greater volatility brings about an increase in land values relative to lands not subject to the restrictions (again, the total marginal effect is not statistically different from zero). While the sign of the effect may seem counterintuitive, it is consistent with the idea that, because of the enhanced ability of farmers to use groundwater substitution, fluctuations in groundwater levels are likely to be more erratic and abrupt for lands not subject to export restrictions. With an export restriction in place, however, volatility in groundwater is plausibly due to a more predictable pattern of drawdown and recharge due to irrigation withdrawals (as evidenced by Figure 4). In this case, increasing water table variability reflects more valuable use of irrigation water. The values of both restricted and unrestricted parcels outside of irrigation districts are not affected by cropland idling. Restricted parcels, however, experience a positive (relative) effect of increases in orchard/vineyard acreage (58% for every percentage point increase), potentially explained by the enhanced water security provided by the export restrictions.

Robustness Checks

In assembling our baseline model specification, several decisions were made with regard to the construction of the explanatory groundwater variables. Included among these decisions are the number of nearest wells used in the inverse-weighted calculation of the groundwater variables, the number of prior years to use when computing the CV, and the choice between the CV and standard deviation. Appendix Tables A2–A4 (A2: all observations, A3: district members, A4: district nonmembers) provide an indication of the sensitivity of our main results to alternative formulations of these variables. The specific changes made to each alternative model specification are (1) using the nearest 10, as opposed to 5, wells in the inverse distance-weighting formula for the groundwater variables; (2) using a 10-year lag in the depth CV calculation; (3) using a 5-year lag of the depth standard deviation, rather than the CV; and (4) using a 10-year lag in the standard deviation calculation, rather than the 5-year CV.

First, we note that the main results pertaining to the drought-period effects are highly robust across all specifications. For the sample as a whole and the district-member subsample, we find that land in restricted counties suffers a decline in land value during the initial drought period (2001–2002), but there is no subsequent differential effect in the later drought period (2007–2009). In addition, the pattern of restricted nondistrict land losing value in the initial drought and unrestricted nondistrict farmers suffering high land value losses during the second drought period also remains unchanged.

The results for the groundwater-related variables are more sensitive to model specification decisions. For the depth to groundwater variable in the full-sample model, we find a negative effect, with at least marginal statistical significance, in all four alternative full-sample specifications. The effect varies from 2.3% to 4.5% for each additional foot of groundwater stock, a range that contains the baseline estimate of 3.8%, with no effect for lands subject to export restrictions. The null effect of groundwater stock we found for the district-members subsample remains in all four alternative regressions. Last, the estimates using the non-district-member subsample show noisier effects, with two of the four estimates (columns (1) and (3) of Table A4) representing effects of 12.3% to 13.8% that are significant at the 10% level. All of the water table variability estimates are indistinguishable from zero in each robustness check. The idled cropland acreage variable generally produces the same (null) effect that we found in the main specification across all alternative model specifications, apart from column (4) of the nonmember results (10-year standard deviation; Appendix Table A4), where it has a negative effect. Since nonmembers should be the least water-secure group of farmers, all else constant, it would be expected that they would suffer the most from idling their land, as they would not be reaping the benefits of water sales. Lastly, we find the same

the marginal effect, reaches far outside the observed range of our data. It is partly for this reason that we explore the sensitivity of our results to alternative specifications of the water table variability measures.

positive (relative) effect of orchard/vineyard acreage in all four non-district-member robustness checks, but no effects in either the district-member or full-sample models.

6. Discussion

As a brief validation check on our estimation results, we compare the initial reductions in land value experienced by farmers subject to the export restrictions to the discounted present value of surface water transactions. Theoretically, if the export restrictions are binding, the reductions in land value should partly reflect the foregone discounted expected net benefits of water exports from these lands. In the first drought of 2001–2002, the value of land subject to an export restriction decreased by 34%, amounting to an average decline of \$2,057. Chaudhry, Fairbanks, and Caldwell (2015) compile data on surface water sales by irrigation districts in Butte County (part of our study area) where the price received for surface water sold in short-term water markets in 2001–2009 was about \$170 per acre-foot, which amounts to a water sale revenue of \$562 per acre.[25] The average participation by farmers in water sales over the 2001–2009 period was about twice every five years. So, in 2001–2002, if the farmers believed they had permanently given up the option of earning \$562 per acre per year from water sales, assuming negligible costs associated with land fallowing (making the \$562 pure economic rent) and a 5% discount rate, the foregone discounted expected net benefit of water sales is \$4,131. This suggests that, during the first period in which the export restrictions were binding, farmers were internalizing roughly 50% of the foregone potential revenue from water sales based on their reported land values. Appendix Table A5 shows the discounted benefits by varying discount rates from 2% to 6% and the participation frequency around the mean observed in the Butte County sample. For higher discount rates or lower participation frequencies, the expected discounted present value of foregone water revenue is closer to our estimated land value differential of \$2,057. We should note that the difference between the two numbers could also reflect the continued ability of farmers to conduct local, within-county transactions under the restrictions, as well as costs associated with land fallowing.[26] Additionally, the discrepancy could also be due to the lower pumping costs brought about by groundwater stock enhancements for farmers in counties with export restrictions.

7. Conclusion

Establishing the appropriate role of groundwater management is challenging given that aquifers have historically been open-access resources for which competing users may have an incentive to extract water at a rate faster than what is socially optimal. With the passage in 2014 of the Sustainable Groundwater Management Act (SGMA) in California, marking the first comprehensive effort to regulate groundwater use in the state, interest in the potential effects of groundwater policy has heightened. Although the motivation and scope of the SGMA is different than that of the export restrictions studied in this paper—SGMA is intended to promote sustainable groundwater use and mitigate the common property externalities that stem from current groundwater management—our study sheds some light on the distributional effects of groundwater policy in the region. In this research, we have shown how localized groundwater export restrictions that were imposed in California throughout the 1990s influence

[25] Only that portion of the proposed transfer that is determined to represent real water savings is transferrable. Depending on the measures used to make water available for a transfer, real water consists primarily of the transferor's reduction in the evapotranspiration of applied water (ETAW), reduction in applied water lost to saline sinks or other unusable sources, or increased releases from storage reservoirs. ETAW for rice in our study area is 3.3 acre-feet per acre (CDWR 2013) which means that, for an average price of \$170 per acre-foot, water sale revenue would be $\$170 \times 3.3 = \$562$ per acre.

[26] According to California Water Code §1745.05 (b), irrigation districts cannot fallow more than 20% of their land for water sales. Participation of district members in enrolling their acres in land fallowing for water sales varies, with some landowners actively participating but others not being very active (Chaudhry, Fairbanks, and Caldwell 2015).

how farmers value their land during drought. The restrictions, along with irrigation district membership, also establish a meaningful delineation in terms of which groups of farmers were most affected by the policies.

While our study design does not fully permit establishing a causal relationship between export restrictions and land values in the traditional program evaluation sense, our results are consistent with policy goals, as well as land and water market fundamentals. Specifically, we find that, for cropland in counties with restrictions, land values declined during the first drought following imposition of the restrictions, a time period when the policies would be expected to be binding. Moreover, we find that this effect was concentrated on land in irrigation districts, areas that are most suitable to export water, while no effect emerged for land outside of irrigation districts. However, this discrepancy in land values goes away in periods marked by more severe drought. These results, coupled with basic trend analysis of groundwater depth in the study area, are consistent with the idea that groundwater management has improved in areas where exports were restricted. At the time when they were adopted, the export restrictions were innovative policy tools, making it plausible that there would be considerable uncertainty on the part of farmers in terms of what effects the policies would have. As such, our results may suggest that the restrictions were not as costly as originally anticipated by farmers, possibly due to their continued ability to conduct local, within-county sales (Hanak 2005).

Additionally, with our panel framework, we find suggestive evidence that reductions in groundwater stock are capitalized into land values. Application of the panel-based methodology we have adopted here holds promise for properly identifying the value of reductions in groundwater stock in more volatile basins, such as those found in southern California. The stock-based interpretation of the estimated groundwater effects was made possible by our use of the panel data from the JAS. While these survey data are a useful source for panel analysis of irrigation water availability and policies, more research is needed on the inherent trade-offs in using different types of farmland values panel data, such as comparing results from repeat sales and survey responses.

A number of important extensions and related questions are left for future research. For one, while our study makes inroads on establishing a causal effect of changes in groundwater stock, there are a number of related applications to which this sort of data could be applied, including a more rigorous assessment of how expectations regarding groundwater levels are built into land values. In addition, we restrict our attention to the Sacramento Valley, which, as a net exporter, generally has a unidirectional flow of water due to transactions. However, export restrictions were also put in place in the southern portions of the state, including the San Joaquin Valley. Studying the effects of export restrictions in the San Joaquin Valley is complicated because of the bidirectional flow of water into and out of the region (i.e., there are many sellers and buyers). Any attempt to tease out the effects of the export restrictions in this region, where water is naturally scarcer, would likely be hindered by the lack of available microdata on surface water deliveries, seniority, and transactions. Therefore, efforts geared toward assembling a comprehensive database on water deliveries, rights, and sales in California would prove fruitful for future research endeavors.

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