# Adjudicated Groundwater Property Rights:

A Structural Model of the Dynamic Game Among Groundwater Users in California*

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**Abstract**

California's farmers and cities rely on groundwater to supply water for irrigation, residential users, and recreation. During much of the state's history, groundwater has operated as an open access resource with no quantified limits on extraction, and several basins in the state have become critically overdrafted. A commonly proposed solution to this problem is the institution of private property rights to groundwater, or quantified limits on extraction, for groundwater users. In this paper we model and analyze the behavior of groundwater users under California's system of dual rights and adjudicated property rights. We first develop a theory model of groundwater extraction and water imports under quantified property rights to identify theoretical sources of inefficiency. We then estimate a structural econometric model of a dynamic game among groundwater users under quantified property rights in which players extract groundwater, drill wells, and import outside water to a group of small groundwater basins. We estimate parameters in the payoff functions by taking advantage of variation in the extraction and water import decisions across a group of municipal water companies, farmers, and other users in the Beaumont Basin in Southern California over a 10-year period following the institution of quantified property rights. We use these parameters to simulate counterfactuals to evaluate the welfare impact of the property rights regime, and to understand the factors either amplified or diminished the impact of the program. Results show that the dual rights system in California creates theoretical sources of inefficiency, and limited the real world effectiveness of the property rights system in practice.

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# 1 Introduction

California's farmers and cities rely on groundwater to supply water for irrigation, residential users, and recreation. During much of the state's history, groundwater has operated as an open access resource with no quantified limits on extraction (Sears et al., 2023b,c), and several basins in the state have become critically overdrafted (California Department of Water Resources, 2016a). As a common pool resource, groundwater suffers from spatial pumping externalities whereby one user's groundwater extraction raises the extraction cost and lowers the total amount available to other nearby users. In addition, if an aquifer receives very little recharge, then groundwater is at least partially a nonrenewable resource (Lin Lawell, 2016; Sears and Lin Lawell, 2019; Sears et al., 2023b).

A commonly proposed solution to this problem is the institution of private property rights to groundwater, or quantified limits on extraction, for groundwater users. In theory this allows market mechanisms to allocate groundwater more efficiently among competing uses. The degree to which common pool resources are inefficiently exploited depends on the ability of rights holders to identify, keep track of, and assert property rights (Sweeney et al., 1971). A well-defined property rights system would define exclusive rights to the stock rather than to a flow from the asset (Lueck, 1995), and would enable groundwater users to internalize any spatial externalities as well, for example by defining exclusive rights to the groundwater stock in the entire aquifer (Bertone Oehninger and Lin Lawell, 2021; Sears et al., 2023a). The first-best groundwater management policy can be complicated and require a high level of monitoring and enforcement, however, rendering it unattractive due to the high economic cost as well as political infeasibility (Guilfoos et al., 2016). Equity concerns may also pose a barrier to the use of property rights for managing common pool resources (Ryan and Sudarshan, 2020).

Groundwater property rights in California are governed by a dual rights system, which is a system with two forms of groundwater property rights. First, the primary right to groundwater is given to the owners of land 'overlying' the resource; these overlying property rights allow owners of the land to beneficially use a reasonable share of any groundwater basin lying below the surface of the land. In most cases in California, overlying property right owners are farmers using groundwater for agricultural irrigation. Second, any groundwater that is unused by the overlying users may then be beneficially used or sold elsewhere by other individuals or businesses through an appropriative right; these appropriators may extract water that is unused by the overlying users to beneficial uses outside of the land. Appropriators may also divert water from multiple basins. In most cases in California, the appropriator is a municipal water district that sells its appropriated groundwater to residential household consumers in their administrative zones (California State Water Resources Control Board, 2017; Bartkiewicz et al., 2006; Sears et al., 2023b,c).

When disputes arise between groundwater users, parties may sue one another over competing claims to property rights and ask the court system to settle their dispute through court adjudication. The adjudication process has long been the primary process for defining groundwater rights in California. In adjudicated basins, the court imposes a watermaster as the regulator for the groundwater basin. In many cases, the watermaster has imposed quantified limits on extraction for individual groundwater users that are consistent with California's dual rights system. These limits act as pumping permits that are frequently tradable and storable over time. Under adjudications, historical extraction is commonly treated as a basis for determining the limits on individual extraction under groundwater management (Landridge et al., 2016).

The allocation of groundwater extraction rights through adjudication in California is an example of a tradable and bankable permit system with free allocation of permits, or "grandfathering". Tradable permits have been proposed and analyzed as a policy instrument for efficiently manage a broad range of pollutants and natural resources (Stavins, 1998; Libecap, 2009; Montgomery, 1972; Fowlie and Perloff, 2013; Ellerman et al., 2000; Kerr and Maré, 1997; Rubin and Kling, 1993). Groundwater has important spatial and dynamic features that limit the effectiveness and efficiency of tradable permit policies, however (Blomquist, 2020). Moreover, features of the dual rights system in California also create additional constraints on the design of tradable permit programs that may make these programs inefficient in theory. An important question that this paper addresses is measuring the empirical magnitude of these constraints on the efficiency of tradable permit policies.

In this paper, we model and analyze the behavior of groundwater users under California's system of dual rights and adjudicated property rights. We first design a theory model of groundwater extraction and water imports under quantified property rights. We show that when spatial externalities are heterogeneous among extractors, and when water districts over-value consumer surplus of their customers relative to water sale profits, extraction may still be socially inefficient even when a market for groundwater rights exists. We also show that when hydrology and well locations create variation in the ability of extractors to access water that they have artificially recharged, property rights systems like those in California may not lead to socially efficient levels of recharge.

We then estimate a structural model of the dynamic game among groundwater users under quantified property rights using data from the Beaumont Basin in the years following implementation of its adjudicated property rights system. We model groundwater users' decisions regarding groundwater extraction, well drilling, and water imports. We use the model to simulate counterfactuals to estimate the welfare impact of the property rights regime, and to understand the factors either amplified or diminished the impact of the program.

Our results show that legal constraints and transaction costs limited water rights trading and efficiency gains. The dual rights system in California creates theoretical sources of inefficiency, and limited the real world effectiveness of the property rights system in practice.

The balance of our paper proceeds as follows. We provide some background on groundwater property rights and the adjudication process in California in Section 2. We review the previous literature in Section 3. We present a simple theory model in Section 4. We discuss our empirical setting and data in Section 5. We describe our structural econometric model in Section 6. We present our results in Section 7. We simulate our counterfactual scenarios in Section 8. We discuss our results and conclude in Section 9.

## 2 Groundwater Property Rights and Adjudication in California

Water rights in California, and the Western US, have developed within a broader context of rapid development of arid land, arising more out of concerns for encouraging the settlement and productive use of arable land than for issues of allocative or dynamic efficiency (Zilberman et al., 2017).

In California, groundwater within a single basin is a common pool resource in which there are different property rights present. Groundwater property rights in California are governed by a dual rights system, which is a system with two forms of groundwater property rights. First, the primary right to groundwater is given to the owners of land 'overlying' the resource; these overlying property rights allow owners of the land to beneficially use a reasonable share of any groundwater basin lying below the surface of the land. In most cases in California, overlying property right owners are farmers using groundwater for agricultural irrigation. Second, any groundwater that is unused by the overlying users may then be beneficially used or sold elsewhere by other individuals or businesses through an appropriative right; these appropriators may extract water that is unused by the overlying users to beneficial uses outside of the land. Appropriators may also divert water from multiple basins. In most cases in California, the appropriator is a municipal water district that sells its appropriated groundwater to residential household consumers in their administrative zones (California State Water Resources Control Board, 2017; Bartkiewicz et al., 2006).[1]

When disputes arise between groundwater users, parties may sue one another over competing claims to property rights and ask the court system to settle their dispute through court adjudication. The adjudication process has long been the primary process for defining groundwater rights in California. An adjudication comes about either as a result of disputes over water districts drawing beyond surplus water, or as a mechanism to plan additions to the local water supply, such as imports from outside the adjudicated area (Landridge et al., 2016). Adjudications have been primarily limited to Southern California, where groundwater resources have been historically more heavily used. They have also increased in number with the introduction of imported water from outside the region (Landridge et al., 2016).

In adjudicated basins, the court imposes a watermaster as the regulator for the groundwater basin. In many cases, the watermaster has imposed quantified limits on extraction for individual groundwater users that are consistent with California's dual rights system. These limits act as pumping permits that are frequently tradable and storable over time. Under adjudications, historical extraction is commonly treated as a basis for determining the limits on individual extraction under groundwater management (Landridge et al., 2016).

[1] A third form of property right, called a prescriptive right, is analogous to "squatter's rights" and can be awarded when a groundwater extractor can prove that they have pumped in a way that is damaging to existing groundwater rights holders for five years (Enion, 2013; Moran and Cravens, 2015).

Historically, the adjudication process has not followed a clear set of guidelines, and often produces results that do not promote great conservation of groundwater. For example, a key concept in adjudication is the determination of sustainable yield, or the quantity of groundwater that can be sustainably withdrawn in a year, and the existence of overdraft, whether or not current extraction exceeds inflow. In their survey of exisiting adjudication judgments, (Landridge et al., 2016) find that definitions used for each of these terms was not constant across judgments, nor were the methods used to measure them. Furthermore, adjudications do not always involve all users in the area, and may not define water rights for all users in their judgments (Landridge et al., 2016). For example, the Santa Paula Basin judgment in Ventura County defined water rights for some appropriators, but then left their rights junior to overlying users (Landridge et al., 2016).

Another issue is that, when the adjudication process results in a determination of groundwater rights, these rights are frequently based on an average of past production by users. Such an allocation of rights does not account for the possibility of different climate conditions in the future, the condition of the aquifer, or changes in each user's demand over time (Landridge et al., 2016). While in some cases rights can be bought or sold, this is not always the case. The tendency to allocate rights based on historical use also creates an incentive structure in which users expecting adjudication have an incentive to withdraw more water in the periods leading up to the adjudication process. This is exacerbated by the institution of mutual prescription, which allows appropriators to gain secure rights in the event that they can demonstrate that they have withdrawn beyond the surplus of the overlyers for five years.

The adjudication process is often lengthy and costly for the parties involved. Water litigation is expensive, and some water disputes have lasted for decades (Babbitt, 2020). For example, the Raymond Basin near Los Angeles took seven years for its initial judgment, and then was appealed for an addition five years (Landridge et al., 2016). The West Coast Basin adjudication had a cost of over $5 million (Landridge et al., 2016). In many adjudications, this is not the end of the process either, as parties may re-enter adjudication, or appeal the court's ruling (Landridge et al., 2016). In order to streamline this process California passed regulations AB 1390 and SB 226 in 2015. The bills require that a stipulated judgment be accepted if it is supported by more than 50 percent of all named parties in the adjudication, and if the supporters include users who held title to at least 75 percent of production in the past 10 years. While this may expedite the process, it could also create an incentive to overpump, since it allocates bargaining power to those with a history of high production. It may also disincentivize the participation of a larger group of users, since this makes the process more onerous for the appropriator bringing suit.

The allocation of groundwater extraction rights through adjudication in California is an example of a tradable and bankable permit system with free allocation of permits, or "grandfathering". Groundwater has important spatial and dynamic features that limit the effectiveness and efficiency of tradable permit policies, however (Blomquist, 2020). Moreover, features of the dual rights system in California also create additional constraints on the design of tradable permit programs that may make these programs inefficient in theory. An important question that this paper addresses is measuring the empirical magnitude of these constraints on the efficiency of tradable permit policies.

As part of the 2014 Sustainable Groundwater Management Act (SGMA), the state has called for the creation of groundwater sustainability agencies (GSAs), which are in large part managed by either individual water districts, or groups of water districts operating in the basin. These groundwater sustainability agencies are empowered under SGMA to allocate groundwater supplies in the basin area (California Department of Water Resources, 2017), but are not empowered to alter groundwater property rights (Blomquist, 2020; Garner et al., 2020). This creates legal risk that allocations defined under SGMA may violate individual property rights claims and be disputed in court (Garner et al., 2020). In other words, any limitations that groundwater sustainability plans place on extraction must be consistent with California's property rights law and its dual rights system as it has been interpreted under common law in California, and able to withstand legal challenges (Babbitt, 2020).

The groundwater sustainability agency has both exclusion and management power within their administrative zone, through its ability to set sustainable yield, and regulate the use of other participants. The water district that is not part of a GSA may lack some of the powers of regulation and exclusion, but due to their scale and the lowering of transaction costs, they have some right to alienation through water transfers. Transaction costs make the rights to exclusion, through adjudication and alienation through water transfer difficult for the individual farmer.

In the case of groundwater in California, the transaction costs related to efficient property right use may in some cases be too high to make them operational at the individual level. In the case of hydraulically connected aquifers spanning more than one user, groundwater flows between plots of land. In addition, there may hydraulic connection between the groundwater aquifer and surface water streams. In this case, identifying one's property right over time is costly at the individual level and prone to error. Making matters worse, once the water flows out of the land underlying the owner's property, the owner's right to use it vanishes. Asserting one's property right by catching an appropriator using beyond their share of surplus water is also difficult, given that monitoring use has not been a requirement for groundwater users. Thus, even in a system of secure property rights, the groundwater user has a strong incentive to use the property right through extraction today, rather than managing it dynamically.

Water trading has historically been viewed with suspicion in California, as smaller extractors fear negative equity effects, and water right holders object to the idea of the auctioning of rights (Zilberman et al., 2017). Ayres et al. (2021) analyze a major aquifer in the Mojave Desert in southern California, and find that groundwater property rights led to substantial net benefits, as capitalized in land values. McLaughlin (2021) finds that basins that formalize property rights experience an improvement in groundwater levels. Rimsaite et al. (2021) examine the degree to which U.S. western water market prices in nine states act as asset pricing theory would predict, and find that water market efficiency is highest in one of the most active U.S. water rights markets located in the Mojave Basin Area, where markets have lower barriers to trade. Nevertheless, Regnacq et al. (2016) find that transfer costs may limit the benefits from tradable water rights in California.

# 3 Literature

## 3.1 Groundwater Property Rights and Tradable Permits

We build on the literature on groundwater property rights and tradable permits.

The degree to which common pool resources are inefficiently exploited depends on the ability of rights holders to identify, keep track of, and assert property rights (Sweeney et al., 1971). A well-defined property rights system would define exclusive rights to the stock rather than to a flow from the asset (Lueck, 1995), and would enable groundwater users to internalize any spatial externalities as well, for example by defining exclusive rights to the groundwater stock in the entire aquifer (Bertone Oehninger and Lin Lawell, 2021; Sears et al., 2023a). The first-best groundwater management policy can be complicated and require a high level of monitoring and enforcement, rendering it unattractive due to the high economic cost as well as political infeasibility (Guilfoos et al., 2016). Equity concerns may also pose a barrier to the use of property rights for managing common pool resources (Ryan and Sudarshan, 2020).

The security of property rights to a common pool resource is predicted to have a positive impact on productive use of the resource (Grossman, 2001). Browne (2018) measures the value created by clarifying property rights for water in Idaho. Tsvetanov and Earnhardt (2020) find that water right retirement in High Priority Areas in Kansas substantially reduced groundwater extraction. In addition, how water rights are measured and bounded within a property rights system can influence water resource development and productivity as well (Smith, 2021).

Tradable permits have long been proposed and analyzed as an alternative to taxes and command and control policies to manage a broad range of pollutants and natural resources (Stavins, 1998; Libecap, 2009; Montgomery, 1972; Fowlie and Perloff, 2013; Ellerman et al., 2000; Kerr and Maré, 1997; Rubin and Kling, 1993). Through the trading of permits, markets can counteract inefficiencies created by externalities by creating an opportunity cost to the behavior (polluting or resource extraction) that does not exist in open access. Moreover, allowing the storage of permits over time provides firms opportunities to hedge risks related to uncertainty over future conditions, and may simplify the policy design (Rubin and Kling, 1993; Ellerman et al., 2000; Kerr and Maré, 1997; Stavins, 2003).

Montgomery (1972) shows that in a static context, emissions permits will generate an efficient equilibrium that minimizes pollution abatement costs in the industry for a given level of pollution, and does not depend on the initial allocation of permits. In this context, firms trade permits to pollute at a market price, bringing the marginal abatement costs across firms to an equal level. Cronshaw and Kruse (1996) extend this analysis to an intertemporal problem where permits may be saved over time, or banked by firms. The authors show that in a perfectly competitive industry without profit regulation, marginal abatement costs should again be equated in each period across firms, and that the present-value price of permits must be non-increasing due to an arbitrage condition. This implies that marginal abatement costs are non-increasing in present terms, and in order for permits to be banked, the present value of marginal abatement costs must remain constant across time periods. Leiby and Rubin (2001) extend this analysis to pollutants whose damages depend both on the flow of present flow emissions and the stock of past emissions. This complicates analysis since social marginal damages of pollution now depend on both the flow level of emissions and a stock value which changes over time. The authors find that an efficient equilibrium is achieved when the efficient total sum of pollution is allocated among firms, and when socially efficient intertemporal trading ratios are imposed. Prices for permits must still satisfy a zero arbitrage condition requiring that they be non-increasing in present value, while intertemporal trading ratios provide a return on stored permits that is determined by the ratio of current stock marginal damages to future stock marginal damages.

A key advantage of tradable permits over emissions taxes is the argument that initial allocations under certain assumptions will not affect the efficiency of outcomes in equilibrium, making it possible for the regulator to use allocation to overcome any political obstacles to regulation (Stavins, 1998). This concept of "acceptability" requires that regulation does not reduce firm profits, and helps explain the prevalence of free allocation policies, or grandfathering of permits (Stavins, 1998). Stavins (1995) points out that initial allocation does affect efficiency though in the case in which transaction costs to trading exist, and thus in order for efficiency to be achieved, the regulator must have detailed knowledge of the costs of compliance for each of the firms involved. Further, Goulder et al. (1997) argue that grandfathering reduces tax revenues that could otherwise be used to remove other more distortionary existing taxes.

Groundwater has important spatial and dynamic features that limit the efficiency of policies that allow for the trading of groundwater rights, however (Blomquist, 2020). For example, groundwater rights that are transferred between users will shift the location of pumping within the basin, and can thus create spatial pumping externalities for nearby users (Nylen et al., 2017). Permit trading must also be set up with an eye to environmental externalities, as damages from seawater intrusion, or subsidence will not be borne only by the purchaser of a groundwater right, but also throughout the basin (Nylen et al., 2017). Finally, improvements in both reporting of groundwater extraction and basin wide conditions must be improved throughout the state. In order for permits to be sustainably allocated, basin managers must be able to understand the physical conditions governing their domains, and whether or not users are abiding by the basin's regulations (Nylen et al., 2017). Furthermore, in the absence of metering, Wallander (2017) notes that farmers may over-irrigate due to an incomplete understanding of how much water has been applied.

Our discussion of groundwater extraction rights in California builds on this discussion by incorporating three new dimensions. First, we incorporate realistic assumptions about spatial heterogenaity in the availability and extraction cost of groundwater, and effects of extraction on the future level of the stock of groundwater. Blomquist (2020) suggests that under spatial heterogenaity, trading will generate costs and benefits across users that are determined by the spatial location of wells, and may not lead to more efficient use. We also incorporate the use of managed artificial recharge in the design of property rights regimes. In property rights regimes like that of our empirical setting, agents are allocated the future right to any water that they import and recharge into the aquifer. This has the effect of fixing an upper bound on the price of permits at the price of water imports which may not be under the control of the regulator. Finally, in our counterfactual analysis we measure the impact of changes to the initial allocation from the historical extraction based grandfathering used in practice.

### 3.2 Structural Econometric Models of Dynamic Games

We also build on the literature on dynamic structural econometric models,[2] and in particular on the literature on structural econometric models of dynamic games. Most models in this literature assume a Markov perfect equilibrium in which players maximize their present discounted value based on expectations about the evolution of state variables (Ericson and Pakes, 1995; Pakes et al., 2007; Aguirregabiria and Mira, 2007; Pesendorfer and Schmidt-Dengler, 2008; de Paula, 2009; Aguirregabiria and Mira, 2010; Srisuma and Linton, 2012; Egesdal et al., 2015; Iskhakov et al., 2016; Adusumilli and Eckardt, 2020; Dearing and Blevins, 2021).[3] In this paper, we apply the structural econometric model of a dynamic game developed by Bajari et al. (2007). This model has also been applied to the cement industry (Ryan, 2012; Fowlie et al., 2016), the world petroleum market (Kheiravar et al., 2023), the production decisions of ethanol producers (Yi et al., 2023), migration decisions (Rojas Valdés et al., 2018, 2023), the global market for solar panels (Gerarden, 2023), calorie consumption (Uetake and Yang, 2018), the digitization of consumer goods (Leyden, 2019), and climate change policy (Zakerinia and Lin Lawell, 2023).

We build in particular on the structural econometric model of the dynamic open access common pool extraction game we developed and estimated in Sears et al. (2023c). While Sears et al. (2023c) focus on modeling extraction decisions during the open access period prior to the institution of property rights, in this paper we extend their analysis to model the extraction, well drilling, artificial recharge,

[2] Structural econometric models of dynamic behavior have been applied to bus engine replacement (Rust, 1987), nuclear power plant shutdown decisions (Rothwell and Rust, 1997), water management (Timmins, 2002), retirement (Iskhakov, 2010), air conditioner purchase behavior (Rapson, 2014), wind turbine shutdowns and upgrades (Cook and Lin Lawell, 2020), copper mining decisions (Aguirregabiria and Luengo, 2016), long-term and short-term decision-making for disease control (Carroll et al., 2023a), the adoption of rooftop solar photovoltaics (Feger et al., 2020; Langer and Lemoine, 2018), supply chain externalities (Carroll et al., 2023b), vehicle scrappage programs (Li et al., 2022), vehicle ownership and usage (Gillingham et al., 2021), urban travel demand (Donna, 2021), agricultural productivity (Carroll et al., 2019), environmental regulations (Blundell et al., 2020), organ transplant decisions (Agarwal et al., 2021), hunting permits (Reeling et al., 2020), agroforestry trees (Oliva et al., 2020), the spraying of pesticides (Yeh et al., 2023; Sambucci et al., 2023), the electricity industry (Cullen, 2015; Cullen et al., 2017; Weber, 2019; Butters et al., 2021), electric vehicles (Hu et al., 2022), forest management (Wu et al., 2023), and deforestation (Araujo et al., 2020).

[3] The model developed by Pakes et al. (2007) has been applied to the multi-stage investment timing game in offshore petroleum production (Lin, 2013), to ethanol investment decisions (Thome and Lin Lawell, 2023), and to the decision to wear and use glasses (Ma et al., 2023). The model developed by Aguirregabiria and Mira (2007) has been applied to oligopoly retail markets (Aguirregabiria et al., 2007). Structural econometric models of dynamic games have also been applied to fisheries (Huang and Smith, 2014), dynamic natural monopoly regulation (Lim and Yurukoglu, 2018), Chinese shipbuilding (Kalouptsidi, 2018), industrial policy (Barwick et al., 2021), coal procurement (Jha, 2020), ethanol investment (Yi and Lin Lawell, 2023b,a), preemption (Fang and Yang, 2023), and the U.S. Supreme Court (Bagwe, 2021).

and imported water sales decisions of groundwater users in the period following the institution of property rights.

# 4 Theory Model

We present a simple model of groundwater extraction and artificial recharge by groundwater users. We then use this model to demonstrate the inefficiency induced by open access, and the role that property rights can play in remedying this inefficiency. We then show how spatial heterogeneity can complicate the optimal design of these policies. We then incorporate the role of artificial recharge. Finally, we show how particular features of the dual rights system in California perform relative to the social optimum.

## 4.1 Extraction Game

In our stylized model, we start by assuming a simple bathtub-type aquifer with a groundwater stock level $S$. There are $N$ groundwater users $i \in \{1, ..., N\}$ who each choose their own extraction $a_i$.

To simplify our analysis, we assume that each groundwater user $i$ has the same extraction cost function $C(a_i, S)$, and that the cost of extraction $C(\cdot)$ to each player $i$ is strictly decreasing in groundwater water $S$, and linear and strictly increasing in player $i$'s extraction $a_i$:

$$C(a_i, S) = (c_1 S + c_2) a_i, \tag{1}$$

where $c_1 < 0$ and $c_2 > 0$, $\frac{\partial C(a_i,S)}{\partial S} = c_1 a_i < 0$, and $\frac{\partial C(a_i,S)}{\partial a_i} = c_1 S + c_2 > 0$. Thus, the marginal lift cost of extraction, $\frac{\partial C(a_i,S)}{\partial a_i} = c_1 S + c_2$, is constant and equal across all players.

We also assume each groundwater user $i$ has the same revenue function $R(a_i)$, where revenues are increasing and strictly concave in player $i$'s extraction $a_i$: $R^{'}(a_i) > 0$ and $R^{''}(a_i) < 0$.

The profit function $\pi(a_i, S)$ is thus the same for each groundwater user $i$, and is given by:

$$\pi(a_i, S) = R(a_i) - C(a_i, S). \tag{2}$$

For the stock we assume that the next period's stock, $S^{'}$, is strictly decreasing in extraction $a_i$ of each groundwater user $i$, and is given by:

$$S^{'}(S, a) = S - a \sum_{i=1}^{N} \delta_i a_i, \tag{3}$$

where $a \equiv (a_1, ..., a_N)$ is a vector of extraction $a_i$ for each groundwater user $i$, and $\delta_i > 0$ represents the magnitude of the negative effects of extraction by groundwater user $i$ on groundwater stock $S$. For the purpose of presenting our results in a simple manner, we assume throughout the model that stock develops deterministically and that model parameters remain constant.

### 4.2 Case 1: Homogeneous Extraction Effects on Stock

In our first case we model a simple game in which the marginal effects of extraction on stock are equal across all players: $\delta_i = \delta_j = \bar{\delta} \quad \forall i, j \in \{1, ...N\}$, where $\bar{\delta} > 0$. In this case, next period's stock $S^{'}$ is given by:

$$S^{'}(S, a) = S - \sum_{i=1}^{N} \delta_i a_i = S - \sum_{i=1}^{N} \bar{\delta} a_i = S - \bar{\delta} A, \tag{4}$$

where $A = \sum_{i=1}^{N} a_i$ is total extraction.

#### 4.2.1 Open Access

Since $N$ is assumed to be large, we assume that each individual groundwater user $i$ treats the entire stock's evolution as exogenously determined. Then under open access each groundwater user profit maximizes in each period since they do not believe they can influence the stock. The first-order condition characterizing behavior is therefore given by:

$$\begin{aligned} \frac{\partial \pi(a_i^{OA}, S)}{\partial a_i} &= 0 \\ \Rightarrow R^{'}(a_i^{OA}) &= c_1 S + c_2 \end{aligned} \tag{5}$$

Thus, marginal revenues equal marginal costs, and $a_i^{OA}$ is equal for each groundwater user $i$.

#### 4.2.2 Social Optimum

We compare open access to the behavior of a social planner. Here we assume that social benefits $\Pi(a, S)$ each period are simply composed of the sum of player payoffs for each player:

$$\Pi(a, S) = \sum_{i=1}^{N} \pi(a_i, S). \tag{6}$$

While each individual groundwater user $i$ treats the entire stock's evolution as exogenously determined, a social planner controlling extraction levels at each well would treat next period's stock as endogenously determined by their extraction choices. The social planner will then choose $a$ in each period to maximize the present discounted value of social benefits. Over an infinite horizon the planner's value function $V^{SP}(S)$ is given by:

$$V^{SP}(S) = \max_{a} \left[ \Pi(a, S) + \beta V^{SP}(S^{'}(S, a)) \right] \tag{7}$$

where $\beta$ is the social planner's discount factor. Taking the first-order condition with respect to $a_i$ yields:

$$
\begin{aligned}
\frac{\partial V^{SP}(S)}{\partial a_i} &= 0 \\
\Rightarrow \frac{\partial \Pi(a^{SP}, S)}{\partial a_i} + \beta \frac{dV^{SP}(S')}{dS} \frac{\partial S'(S, (a_i^{SP}, a_{-i}^{SP}))}{\partial a_i} &= 0 \\
\Rightarrow \frac{\partial \pi(a_i^{SP}, S)}{\partial a_i} - \beta\bar{\delta} \frac{dV^{SP}(S')}{dS} &= 0 \\
\Rightarrow \frac{\partial \pi(a_i^{SP}, S)}{\partial a_i} &= \beta\bar{\delta} \frac{dV^{SP}(S')}{dS} \\
\Rightarrow R'(a_i^{SP}) = c_1 S + c_2 + \beta\bar{\delta} &\frac{dV^{SP}(S'(S, (a_i^{SP}, a_{-i}^{SP}))}{dS}
\end{aligned}
\tag{8}
$$

Thus, the first-order condition is equal at each well, implying that extraction is also equal at each well.

If we make the reasonable assumption that $V^{SP}(S)$ is increasing in $S$, then by comparing the first-order condition (5) under open access with the first-order condition (8), we see that $R'(a_i^{SP}) > R'(a_i^{OA})$. Since marginal revenue is decreasing in extraction, this means that extraction is higher under open access than under the social optimum for each groundwater user $i$: $a_i^{OA} > a_i^{SP}$. Since extraction levels are equal across players in both the open access case and the social planner problem, this implies that total extraction is higher under open access than the socially optimal level: $A^{OA} > A^{SP}$. As a result, social welfare under open access must be lower than socially optimal.

We can also derive the marginal social value of groundwater stock $S$ by taking the derivative of the value function with respect to $S$:

$$
\begin{aligned}
\frac{dV^{SP}(S)}{dS} &= \frac{\partial \Pi(a^{SP}, S)}{\partial S} + \beta \frac{dV^{SP}(S')}{dS} \frac{\partial S'(S, a^{SP})}{\partial S} \\
\Rightarrow \frac{dV^{SP}(S)}{dS} &= \frac{\partial \Pi(a^{SP}, S)}{\partial S} + \beta \frac{dV^{SP}(S')}{dS} \\
\Rightarrow \frac{dV^{SP}(S)}{dS} &= \frac{\partial \Pi(a^{SP}, S)}{\partial S} + \frac{1}{\bar{\delta}} \frac{\partial \pi(a_i^{SP}, S)}{\partial a_i} \\
\Rightarrow \frac{dV^{SP}(S)}{dS} &= \underbrace{-\sum_{i=1}^{N} \left[ \frac{\partial C(a_i, S)}{\partial S} \right]}_{>0} + \frac{1}{\bar{\delta}} \frac{\partial \pi(a_i^{SP}, S)}{\partial a_i}
\end{aligned}
\tag{9}
$$

In other words, the value of an additional unit of $S$ in the ground today equals the aggregate effect it would have on the costs for all players today, plus the discounted value of an additional unit of $S$ in the ground tomorrow. From the first-order condition for the social planner, the discounted value of an additional unit of $S$ in the ground tomorrow is given by the marginal profits from extraction today divided by the marginal effect $\bar{\delta}$ of extraction today on stock tomorrow. Thus, the value of an additional unit of $S$ in the ground today equals the aggregate effect it would have on the costs for all players today, plus the marginal profits from extraction today divided by the marginal effect $\bar{\delta}$ of extraction today on stock tomorrow. This insight holds generally for the social planner throughout our theory model.

From our condition for the value of an additional unit of $S$ and our first-order condition for extraction, we can then derive the optimal path of extraction to be governed by the following condition:

$$\begin{aligned}
\frac{\partial \pi(a_i^{SP}, S)}{\partial a_i} &= \beta\bar{\delta}\frac{dV^{SP}(S^{'})}{dS} \\
\Rightarrow \frac{\partial \pi(a_i^{SP}, S)}{\partial a_i} &= \beta\bar{\delta}\left(-\sum_{i=1}^{N}\left[\frac{\partial C(a_i, S^{'})}{\partial S}\right] + \frac{1}{\bar{\delta}}\frac{\partial \pi(a_i^{SP}, S^{'})}{\partial a_i}\right) \\
\Rightarrow \frac{\partial \pi(a_i^{SP}, S)}{\partial a_i} &= -\beta\bar{\delta}\sum_{i=1}^{N}\left[\frac{\partial C(a_i, S^{'})}{\partial S}\right] + \beta\frac{\partial \pi(a_i^{SP}, S^{'})}{\partial a_i} \\
\Rightarrow \frac{\partial \pi(a_i^{SP}, S)}{\partial a_i} - \beta\frac{\partial \pi(a_i^{SP}, S^{'})}{\partial a_i} &= \underbrace{-\beta\bar{\delta}\sum_{i=1}^{N}\left[\frac{\partial C(a_i, S^{'})}{\partial S}\right]}_{>0}.
\end{aligned} \tag{10}$$

### 4.2.3 Policy Instruments

We can then envision a regulator, tasked with the purpose of maximizing social welfare, designing a system of taxes, or equivalently extraction permits, and transfers each period. Clearly if possible the regulator would choose either a per-unit tax, or a cap on total extraction, in each period such that the quantity of extraction at each well induced by the policy instrument, $a_i^{\tau}$, equals extraction determined by the social planner problem, $a_i^{SP}$. For the purpose of clarity, we will have the regulator choose a system of taxes and transfers. Capping total extraction and allocating tradeable permits, or extraction rights, in each period would also produce equivalent results. Here we assume that all tax revenues are re-distributed through equal transfers to the players each period. Thus, since $N$ is assumed to be large, we assume that players do not account for their influence on transfers when making their extraction choices.

If $\tau(S)$ represents the per-unit extraction tax charged to the players at a stock level of $S$, then the profit function for each player becomes:

$$\pi(a_i, S) = R(a_i) - C(a_i, S) - \tau(S)a_i. \tag{11}$$

Again, players maximize period profits. This generates the first-order condition which characterizes extraction levels under the tax system:

$$\begin{aligned}
\frac{\partial \pi(a_i^{\tau}, S)}{\partial a_i} &= \tau(S) \\
\Rightarrow R^{'}(a_i^{\tau}) &= c_1 S + c_2 + \tau(S).
\end{aligned} \tag{12}$$

From the first-order condition (12) under the tax system and the first-order condition (8) of the social planner, it is clear that an optimal tax of $\tau(S) = \beta\bar{\delta}\frac{dV^{SP}(S'(S,(a_i^{SP},a_{-i}^{SP}))}{dS}$ will make the first-order conditions equivalent for each player, and thus set extraction levels equal to socially optimal levels. Since tax revenues are re-distributed, they have no net effect on social welfare. Thus, under this system of taxes and transfers we would observe socially efficient extraction and social welfare.

Our results in Case 1 indicate a role for the regulator in designing socially efficient taxes that can induce private players to behave in a socially efficient manner. These results rely, however, on a key assumption in our model of homogeneous extraction effects on the stock $S$. Thus each player's extraction produces the same marginal social damages through depleting the stock at a common rate.

## 4.3 Case 2: Spatial Heterogeneity

The assumption we made in Case 1 of homogeneous extraction effects on the stock $S$ is an unrealistic assumption in many cases. Factors like the transmissivity of soil, the presence of fault lines, and conjunctive flows between groundwater and surface water create heterogeneity across space in the degree to which one player's extraction affects the stock of groundwater available to other players in the game. To model this, we now allow the marginal effects $\delta_i$ of extraction $a_i$ on stock $S$ to differ for each player $i$.

### 4.3.1 Social Optimum

Examining the first-order condition of the social planner, we see that when the marginal effects $\delta_i$ of extraction $a_i$ on stock $S$ vary for each player $i$, then there is a separate first-order condition for each player $i$ that characterizes player $i$'s socially efficient extraction $a_i^{SP}$:

$$\begin{aligned} \frac{\partial V^{SP}(S)}{\partial a_i} &= 0 \\ \Rightarrow \frac{\partial \Pi(a^{SP},S)}{\partial a_i} + \beta\frac{\partial V^{SP}(S')}{\partial S}\frac{\partial S'(S,(a_i^{SP},a_{-i}^{SP}))}{\partial a_i} &= 0 \\ \Rightarrow \frac{\partial \pi(a_i^{SP},S)}{\partial a_i} - \beta\delta_i\frac{\partial V^{SP}(S')}{\partial S} &= 0 \\ \Rightarrow \frac{\partial \pi(a_i^{SP},S)}{\partial a_i} &= \beta\delta_i\frac{\partial V^{SP}(S')}{\partial S}. \end{aligned} \tag{13}$$

When the marginal effects $\delta_i$ of extraction $a_i$ on stock $S$ vary for each player $i$, socially efficient extraction $a_i^{SP}$ is no longer equal across players. Note that the term $\frac{\partial V^{SP}(S')}{\partial S}$ is equal across all players, since the stock is shared by everyone. This means that the marginal social damages from extraction will differ across players with different values of $\delta_i$, or different marginal extraction effects on the stock.

### 4.3.2 Policy Instruments

Since the marginal effects $\delta_i$ of extraction $a_i$ on stock $S$ vary for each player $i$, ideally the regulator would like to set a different tax level for each player $i$. The regulator is constrained, however, to just choosing one tax $\tau(S)$ on extraction for all players. This is in keeping with a regulator constrained to just allocating a total quantity of permits, and is realistic in our context, since determining the marginal social damages from extraction for each player in each year is likely infeasible. So, the regulator must choose a single tax level $\tau(S)$ for all players each period. This generates the same first-order condition as in Case 1. Thus, extraction in the system will be equal across players, and thus will no longer be socially efficient. Choosing an optimal tax depends then on the distribution of $\delta$ across the players. In a more homogenous system we would expect the welfare loss relative to the social optimum to be small, while in a heterogeneous system we would expect larger inefficiencies.

## 4.4 Case 3: Artificial Recharge

In California a popular policy to maintain the stock of groundwater in a basin is the use of imported water supplies for managed artificial recharge. These are expensive projects that require significant public investment. In our model, we incorporate recharge through a variable $R$. The cost $C_R(R)$ of recharge is assumed to be increasing in $R$ and convex, and is given by:

$$C_R(R) = c_{R0} + c_{R1}R + c_{R2}R^2, \tag{14}$$

where $c_{R0} > 0$, $c_{R1} > 0$, and $c_{R2} > 0$, and therefore $C_R^{'}(R) > 0$ and $C_R^{''}(R) > 0$.

Recharge is assumed to have a positive linear effect on the stock $S$. The next period's stock, $S^{'}$, is now given by:

$$S^{'}(S, a, R) = S - \sum_{i=1}^{N} \delta_i a_i + \gamma R, \tag{15}$$

where $\gamma > 0$ represents the positive linear effect on recharge $R$ on groundwater stock $S$ and, as before, $\delta_i > 0$ represents the negative effects of extraction by groundwater user $i$ on groundwater stock $S$. For the purpose of presenting our results in a simple manner, we assume throughout the model that stock develops deterministically and that model parameters remain constant.

We assume that players cannot individually purchase water for artificial recharge under open access. Instead we focus our analysis on the behavior of the regulator relative to the social optimum.

### 4.4.1 Social Optimum

Social welfare now includes the cost of funding artificial recharge in addition to the sum of player profits. The social planner's Bellman equation is now:

$$SP_V^{SP}(S) = \max_a \left[\Pi(a, S) - C_R(R) + \beta V^{SP}(S^{'}(S, a, R))\right]. \tag{16}$$

The social planner now has one additional first-order condition which characterizes the optimal level of recharge. The first-order condition for extraction is now given by:

$$\begin{aligned}
\frac{\partial V^{SP}(S)}{\partial a_i} &= 0 \\
\Rightarrow \frac{\partial \Pi(a^{SP}, S)}{\partial a_i} + \beta \frac{\partial V^{SP}(S')}{\partial S} \frac{\partial S'(S, (a_i^{SP}, a_{-i}^{SP}), R^{SP})}{\partial a_i} &= 0 \\
\Rightarrow \frac{\partial \pi(a_i^{SP}, S)}{\partial a_i} - \beta \delta_i \frac{\partial V^{SP}(S')}{\partial S} &= 0 \\
\Rightarrow \frac{\partial \pi(a_i^{SP}, S)}{\partial a_i} = \beta \delta_i \frac{\partial V^{SP}(S')}{\partial S}&,
\end{aligned} \tag{17}$$

and the first-order condition for recharge is given by:

$$\begin{aligned}
\frac{\partial V^{SP}(S)}{\partial R} &= 0 \\
\Rightarrow -C_R'(R^{SP}) + \beta \frac{\partial V^{SP}(S')}{\partial S} \frac{\partial S'(S, a^{SP}, R^{SP})}{\partial R} &= 0 \\
\Rightarrow -C_R'(R^{SP}) + \beta \gamma \frac{\partial V^{SP}(S')}{\partial S} &= 0 \\
\Rightarrow C_R'(R^{SP}) = \beta \gamma \frac{\partial V^{SP}(S')}{\partial S} &= 0.
\end{aligned} \tag{18}$$

The social planner then would set recharge such that its marginal cost equals the marginal social benefits it would provide in future years by bolstering the stock. Clearly the degree to which artificial recharge infiltrates the stock will tend to directly affect the optimal level of recharge, as will the convexity of the cost curve for recharge.

The marginal social value of groundwater stock, $\frac{\partial V^{SP}(S)}{\partial S}$, is given by:

$$\begin{aligned}
\frac{\partial V^{SP}(S)}{\partial S} &= \frac{\partial \Pi(a^{SP}, S)}{\partial S} + \beta \frac{\partial V^{SP}(S')}{\partial S} \frac{\partial S'(S, a^{SP}, R^{SP})}{\partial S} \\
\Rightarrow \frac{\partial V^{SP}(S)}{\partial S} &= \frac{\partial \Pi(a^{SP}, S)}{\partial S} + \beta \frac{\partial V^{SP}(S')}{\partial S} \\
\Rightarrow \frac{\partial V^{SP}(S)}{\partial S} &= \frac{\partial \Pi(a^{SP}, S)}{\partial S} + \frac{1}{\delta_i} \frac{\partial \pi(a_i^{SP}, S)}{\partial a_i} \\
\Rightarrow \frac{\partial V^{SP}(S)}{\partial S} &= \underbrace{-\sum_{i=1}^{N} \left[ \frac{\partial C(a_i, S)}{\partial S} \right]}_{>0} + \frac{1}{\delta_i} \frac{\partial \pi(a_i^{SP}, S)}{\partial a_i}.
\end{aligned} \tag{19}$$

### 4.4.2 Policy Instruments

Turning to the regulator's problem, we first examine the simpler case in which extraction has homogeneous effects across space. Clearly there exists an optimal tax $\tau(S)$ that will induce efficient extraction levels. The socially efficient tax correlates with the marginal social value of groundwater stock, $\frac{\partial V^{SP}(S)}{\partial S}$, given in Equation (19).

The regulator can then choose recharge levels equivalent to the social planner, but the total tax revenue $T^{\tau}(S) = \tau(S)A^{\tau}(S)$ does not necessarily align with the cost $C(R^{\tau})$ of recharge. If revenues exceed the cost of recharge then the excess revenues can simply be transferred back to the players as in the extraction only version of the regulator problem. When revenues do not meet the cost of recharge, however, the regulator is required to tax the players.

## 4.5 Case 4: The Dual Rights System

We now model particular features of the dual rights system in California and use our previous analysis to draw theoretical predictions about when it may perform more or less efficiently. Here we conduct analyses of both overlying and appropriator rights holders. We allow for both spatial heterogeneity and artificial recharge. The social optimum is therefore the social optimum described in Section 4.4.1, and is characterized by the first-order conditions in Equations (17) and (18), with the marginal social value of groundwater stock given in Equation (19).

### 4.5.1 Overlyers

Groundwater extractors in California who use water on their land have an overlying right to the groundwater that lies below their land. This entitles them to use groundwater for reasonable and beneficial uses. In practice under an adjudication, these rights holders are given recurring rights to an extraction limit that correlates the share of the basin that their land covers. These rights are tied to the land and are often more difficult to trade than rights held by appropriators. To model these rights we assume that a subset of players, $i = 1, ...N_O$ are overlyers, each with an extraction limit (or permitted quantity) $L_i$. This limit does not change across different levels of the stock $S$. Then each player solves a static constrained profit maximization problem:

$$\begin{aligned} a_i^O = max_{a_i} \pi(a_i, S) \\ s.t. \quad a_i \leq L_i. \end{aligned}$$

Thus we see that this leads to extraction quantities that are identical with those found under open access whenever $a_i^{OA} <= L_i$. Otherwise the constraint binds and the player extracts their limit $L_i$. Since the player cannot influence their right in the next period there is no incentive to limit extraction in the present. Moreover, since the quantity does not vary with the level of stock $S$, players may not be able to extract more at higher levels of stock when it is more profitable to do so. Indeed in order for the system to produce socially efficient behavior by overlyers, the quantity limits must be at the socially optimal extraction levels for the stock $S$, and artificial recharge $R$ must exactly offset the effects of extraction, so that the $S$ remains constant at a steady state.

Another reason to doubt the effectiveness of overlying rights to induce socially efficient extraction is due to how they are frequently allocated in practice. As shown, these rights systems are expected to perform most efficiently when stock is relatively stable, and the $P$ values are close to $a^{SP}$. In a case of spatial heterogeneity this would require that the permitted quantity $L_i$ is highly correlated with the marginal effect $\delta_i$ of extraction $a_i$ on stock $S$ across players $i$. In practice though, adjudications have often allocated these rights based on a share of an estimate of safe yield, or the maximum quantity of extraction in the system that will not exceed long term recharge. Shares are often determined by the relative sizes of land ownership or historical levels of extraction. Safe yield estimates have in some cases used levels of extraction during periods in which stock was relatively stable. This may not be an accurate representation of safe yield if factors that influence recharge like climate and land use are expected to change in the future. Historical extraction and land ownership are not necessarily highly correlated with soil transmissivity and other hydrological factors that influence the stock effects summarized by $\delta_i$. Therefore, in a context of spatial heterogeneity, with uncertainty over the long term path of recharge, we would not expect policy instruments like overlying rights to perform well.

#### 4.5.2 Appropriators

Groundwater users in California who extract water in one location for use in another location draw on appropriative groundwater rights. This entitles them to any water deemed surplus to water used by overlyers. In adjudications including the empirical setting of this paper in the Beaumont Basin, appropriators are given an initial allocation of water rights that can be traded to other appropriators. In the context of artificial recharge, appropriators are frequently given additional water rights when they import water for the purpose of recharge. These rights can be save over time, but do not get re-allocated like in the case of overlying rights. In many cases the small size of property rights systems make trading infrequent, and appropriators operate primarily through the artificial recharge channel to supplement their water rights. Thus, each period the price $p_L$ of water rights is equal to the price $p_R$ of recharge.

We assume that players still view the stock as evolving exogenously, but that they now build in expectations about their own private stocks of water rights $L_i$ as well. Here we assume that player $i$'s stock of private water rights next period, $L_i^{'}$, is given by:

$$L_i^{'}(L_i, a_i, l_i) = L_i - a_i + l_i, \tag{20}$$

where $l_i$ is the number of water rights purchased.

Each player $i$'s Bellman equation is given by:

$$V_i^P(S, L_i, p_L) = \max_{a_i, l_i} \left[\pi(a_i, S) - p_L l_i + \beta V_i^P(S^{'}, P^{'}(L_i, a_i, l_i), p_L^{'})\right]$$
$$s.t. \quad a_i \leq L_i,$$

where $p_L$ is the price of water rights, which we assume each player $i$ takes as given.

Then the player has the following first-order condition for extraction $a_i$:

$$
\begin{aligned}
\frac{\partial \pi(a_i^P, S)}{\partial a_i} + \beta \frac{\partial V_i^P(S', L_i', p_L')}{\partial S} \frac{\partial S'(S, (a_i^P, a_{-i}^P), R^P)}{\partial a_i} + \beta \frac{\partial V_i^P(S', L_i'(L_i, a_i^P, l_i^P), p_L')}{\partial L_i} \frac{\partial L_i'(L_i, a_i^P, l_i^P)}{\partial a_i} &= 0 \\
\Rightarrow \frac{\partial \pi(a_i^P, S)}{\partial a_i} - \beta \delta_i \frac{\partial V_i^P(S', L_i', p_L')}{\partial S} - \beta \frac{\partial V_i^P(S', L_i'(L_i, a_i^P, l_i^P), p_L')}{\partial L_i} &= 0 \\
\Rightarrow \frac{\partial \pi(a_i^P, S)}{\partial a_i} = \beta \delta_i \frac{\partial V_i^P(S', L_i', p_L')}{\partial S} + \beta \frac{\partial V_i^P(S', L_i'(L_i, a_i^P, l_i^P), p_L')}{\partial L_i}
\end{aligned}
\tag{21}
$$

and the following first-order condition for water rights purchased $l_i$:

$$
\begin{aligned}
\frac{\partial \pi(a_i^P, S)}{\partial l_i} + \beta \frac{\partial V_i^P(S', L_i'(L_i, a_i^P, l_i^P), p_L')}{\partial L_i} \frac{\partial L_i'(L_i, a_i^P, l_i^P)}{\partial l_i} &= 0 \\
\Rightarrow -p_L + \beta \frac{\partial V_i^P(S', L_i'(L_i, a_i^P, l_i^P), p_L')}{\partial L_i} &= 0 \\
\Rightarrow p_L = \beta \frac{\partial V_i^P(S', L_i'(L_i, a_i^P, l_i^P), p_L')}{\partial L_i}&.
\end{aligned}
\tag{22}
$$

Combining Equations (21) and (22), we obtain the following optimality condition for each player $i$ at an interior solution:

$$
\begin{aligned}
\frac{\partial \pi(a_i^P, S)}{\partial a_i} &= \beta \delta_i \frac{\partial V_i^P(S', L_i', p_L')}{\partial S} + p_L \\
\Rightarrow p_L &= \frac{\partial \pi(a_i^P, S)}{\partial a_i} - \beta \delta_i \frac{\partial V_i^P(S', L_i', p_L')}{\partial S}.
\end{aligned}
\tag{23}
$$

Next we can solve for the marginal value of stock to player $i$ in the period at an interior solution by taking the derivative of the value function with respect to $S$:

$$
\begin{aligned}
\frac{\partial V_i^P(S, L_i, p_L)}{\partial S} &= \frac{\partial \pi(a_i^P, S)}{\partial S} + \beta \frac{\partial V_i^P(S', L_i', p_L')}{\partial S} \frac{\partial S'(S, (a_i^P, a_{-i}^P), R^P)}{\partial S} \\
\Rightarrow \frac{\partial V_i^P(S, L_i, p_L)}{\partial S} &= -\frac{\partial C(a_i, S)}{\partial S} + \beta \frac{\partial V_i^P(S', L_i', p_L')}{\partial S} \\
\Rightarrow \frac{\partial V_i^P(S, L_i, p_L)}{\partial S} &= -\frac{\partial C(a_i, S)}{\partial S} + \frac{1}{\delta_i} \left( \frac{\partial \pi(a_i^P, S)}{\partial a_i} - p_L \right)
\end{aligned}
\tag{24}
$$

Next we can solve for the marginal value of additional water rights to player $i$ in the period at an interior solution by taking the derivative of the value function with respect to $L_i$:

$$\begin{aligned}
&\frac{\partial V_i^P(S, L_i, p_L)}{\partial L_i} = \beta \frac{\partial V_i^P(S^{'}, L_i^{'}(L_i, a_i^P, l_i^P), p_L^{'})}{\partial L_i} \frac{\partial L_i^{'}(L_i, a_i^P, l_i^P)}{\partial L_i} \\
\Rightarrow &\frac{\partial V_i^P(S, L_i, p_L)}{\partial L_i} = \beta \frac{\partial V_i^P(S^{'}, L_i^{'}(L_i, a_i^P, l_i^P), p_L^{'})}{\partial L_i} \\
\Rightarrow &\frac{\partial V_i^P(S, L_i, p_L)}{\partial L_i} = p_L \\
\Rightarrow &\frac{\partial V_i^P(S, L_i, p_L)}{\partial L_i} = \frac{\partial \pi(a_i^P, S)}{\partial a_i} - \beta \delta_i \frac{\partial V_i^P(S^{'}, L_i^{'}, p_L^{'})}{\partial S}.
\end{aligned} \tag{25}$$

We can then obtain the condition that governs the trajectories of extraction, recharge, and the price of water rights for an interior solution to exist:

$$\begin{aligned}
&\frac{\partial V_i^P(S, L_i, p_L)}{\partial L_i} = \beta \frac{\partial V_i^P(S^{'}, L_i^{'}(L_i, a_i^P, l_i^P), p_L^{'})}{\partial L_i} \\
&\Rightarrow p_L = \beta p_L^{'}
\end{aligned} \tag{26}$$

Thus, the price of water rights follows the Hotelling rule (Hotelling, 1931) and increases at the rate of interest $r = \left(\frac{1}{\beta} - 1\right)$, where $\beta = \frac{1}{1+r}$. The intuition here is straightforward. If the price is expected to grow faster than the rate of interest $r$, then the players will wish to accumulate more water rights in the present if they expect to purchase rights in the next period. To do this they can either purchase more rights in the present or adjust their extraction. If the player extracts slightly less in the current period, then they would preserve the right to that extraction in the future period when it will earn a higher return at the margin. Alternatively, they could simply purchase more water rights in the current period and then extract more in the future period without having to raise their water rights purchases when the rights are more expensive. Either deviation would improve the player's total expected profits, and would violate the assumption that their current extraction plan is privately optimal. In each case the optimal behavior will untether extraction from the current period's price for water rights. Thus, even if a water rights scheme is devised to match the price of water rights with the social cost of extraction in the period, if this social cost does not rise at a discount rate $r$ that corresponds to the social planner's discount factor $\beta$, we will not observe socially efficient behavior.

The socially efficient tax correlates with the marginal social value of groundwater stock, $\frac{\partial V^{SP}(S)}{\partial S}$, given in Equation (19). For the marginal social value of groundwater stock and thus the socially efficient price of water rights to grow at the rate $r = \left(\frac{1}{\beta} - 1\right)$, there must be no net stock effects on social profits in the current period. Clearly this can not be the case, since $S$ enters the cost function for each player, and the first term on the right side is likely to be positive unless a rise in stock causes users to dramatically reduce their extraction in the present. Then clearly the social planner's price rises at a rate less than $r = \left(\frac{1}{\beta} - 1\right)$. Therefore water rights pricing in the dual rights system must incorporate an intertemporal constraint that limits the effectiveness of the policy to maximize social net benefits in any period. While the ability to save water rights does promote a form of dynamic optimization by players, the dynamics are tied to the player's private stock of water rights, which does not correspond to the shared stock of groundwater.

### 4.5.3 Policy Instruments

We treat the price $p_L$ of water rights and the quantity of recharge $R$ imported as the policymaker's instruments. Any net revenues from the water rights purchases and recharge costs are transferred equally across players.

The policymaker needs to choose from a subset of price paths for water rights that satisfy the constraint of growing at the rate $r = \left(\frac{1}{\beta} - 1\right)$. To achieve maximum efficiency in our simple case of spatial homogeneity, they would like to balance the efficiency of extraction across periods. Since the price of water rights grows faster than the marginal social value of groundwater stock, this means that the price of water rights cannot remain equal to the marginal social value of groundwater stock, or the socially optimal tax discussed in our previous exercise under the current rules of the property rights regime. Leiby and Rubin (2001) use a similar discussion in the context of stock pollutants to motivate the design of intertemporal trading ratio for stored permits. In other words, to allow for permit prices to grow at the discount rate $r$, players should receive a return on stored permits in the next period.

Let's therefore also consider an additional policy instrument for the policymaker, the intertemporal trading ratio $\beta_{L,i}$ for stored permits, wherein each player $i$ receives $\beta_{L,i}$ permits in the next period for each permit saved in the present.

From Equation (9) for the marginal social value of groundwater stock in the case of homogenous extraction effects on stock, we find that the marginal social value of groundwater stock grows at the rate:

$$\begin{aligned}
\frac{\frac{\partial V^{SP}(S')}{\partial S} - \frac{\partial V^{SP}(S)}{\partial S}}{\frac{\partial V^{SP}(S)}{\partial S}} &= \frac{1}{\beta}\left(1 - \frac{\frac{\partial \Pi(a^{SP},S)}{\partial S}}{\frac{\partial V^{SP}(S)}{\partial S}}\right) - 1 \\
\Rightarrow \frac{\frac{\partial V^{SP}(S')}{\partial S} - \frac{\partial V^{SP}(S)}{\partial S}}{\frac{\partial V^{SP}(S)}{\partial S}} &= \frac{1}{\beta}\left(1 - \frac{\frac{\partial \Pi(a^{SP},S)}{\partial S}}{\frac{\partial \Pi(a^{SP},S)}{\partial S} + \frac{1}{\delta}\frac{\partial \pi(a_i^{SP},S)}{\partial a_i}}\right) - 1.
\end{aligned} \tag{27}$$

If we alter the equation of motion for each player's stock of permits so that they receive $\beta_{L,i}$ permits in the next period for each permit saved in the present, then that player $i$'s stock of private water rights next period, $L_i'$, is now given by:

$$L_i'(L_i, a_i, l_i) = \beta_{L,i}\left(L_i - a_i + l_i\right), \tag{28}$$

Player $i$ then has the following first-order condition for extraction $a_i$:

$$\begin{aligned}
\frac{\partial \pi(a_i^P, S)}{\partial a_i} + \beta \frac{\partial V_i^P(S', L_i', p_L')}{\partial S} \frac{\partial S'(S, (a_i^P, a_{-i}^P), R^P)}{\partial a_i} + \beta \frac{\partial V_i^P(S', L_i'(L_i, a_i^P, l_i^P), p_L')}{\partial L_i} \frac{\partial L_i'(L_i, a_i^P, l_i^P)}{\partial a_i} &= 0 \\
\Rightarrow \frac{\partial \pi(a_i^P, S)}{\partial a_i} - \beta \delta_i \frac{\partial V_i^P(S', L_i', p_L')}{\partial S} - \beta \beta_{L,i} \frac{\partial V_i^P(S', L_i'(L_i, a_i^P, l_i^P), p_L')}{\partial L_i} &= 0 \\
\Rightarrow \frac{\partial \pi(a_i^P, S)}{\partial a_i} = \beta \delta_i \frac{\partial V_i^P(S', L_i', p_L')}{\partial S} + \beta \beta_{L,i} \frac{\partial V_i^P(S', L_i'(L_i, a_i^P, l_i^P), p_L')}{\partial L_i}
\end{aligned} \tag{29}$$

and the following first-order condition for water rights purchased $l_i$:

$$\begin{aligned}
\frac{\partial \pi(a_i^P, S)}{\partial l_i} + \beta \frac{\partial V_i^P(S', L_i'(L_i, a_i^P, l_i^P), p_L')}{\partial L_i} \frac{\partial L_i'(L_i, a_i^P, l_i^P)}{\partial l_i} &= 0 \\
\Rightarrow -p_L + \beta \beta_{L,i} \frac{\partial V_i^P(S', L_i'(L_i, a_i^P, l_i^P), p_L')}{\partial L_i} &= 0 \\
\Rightarrow p_L = \beta \beta_{L,i} \frac{\partial V_i^P(S', L_i'(L_i, a_i^P, l_i^P), p_L')}{\partial L_i}.
\end{aligned} \tag{30}$$

Combining Equations (29) and (30), we obtain the following optimality condition for each player $i$ at an interior solution:

$$\begin{aligned}
\frac{\partial \pi(a_i^P, S)}{\partial a_i} &= \beta \delta_i \frac{\partial V_i^P(S', L_i', p_L')}{\partial S} + p_L \\
\Rightarrow p_L &= \frac{\partial \pi(a_i^P, S)}{\partial a_i} - \beta \delta_i \frac{\partial V_i^P(S', L_i', p_L')}{\partial S}.
\end{aligned} \tag{31}$$

Next we can solve for the marginal value of stock to player $i$ in the period at an interior solution by taking the derivative of the value function with respect to $S$:

$$\begin{aligned}
\frac{\partial V_i^P(S, L_i, p_L)}{\partial S} &= \frac{\partial \pi(a_i^P, S)}{\partial S} + \beta \frac{\partial V_i^P(S', L_i', p_L')}{\partial S} \frac{\partial S'(S, (a_i^P, a_{-i}^P), R^P)}{\partial S} \\
\Rightarrow \frac{\partial V_i^P(S, L_i, p_L)}{\partial S} &= -\frac{\partial C(a_i, S)}{\partial S} + \beta \frac{\partial V_i^P(S', L_i', p_L')}{\partial S} \\
\Rightarrow \frac{\partial V_i^P(S, L_i, p_L)}{\partial S} &= -\frac{\partial C(a_i, S)}{\partial S} + \frac{1}{\delta_i}\left(\frac{\partial \pi(a_i^P, S)}{\partial a_i} - p_L\right)
\end{aligned} \tag{32}$$

Next we can solve for the marginal value of additional water rights to player $i$ in the period at an interior solution by taking the derivative of the value function with respect to $L_i$:

$$\begin{aligned}
\frac{\partial V_i^P(S, L_i, p_L)}{\partial L_i} &= \beta \frac{\partial V_i^P(S^{'}, L_i^{'}(L_i, a_i^P, l_i^P), p_L^{'})}{\partial L_i} \frac{\partial L_i^{'}(L_i, a_i^P, l_i^P)}{\partial L_i} \\
\Rightarrow \frac{\partial V_i^P(S, L_i, p_L)}{\partial L_i} &= \beta \beta_{L,i} \frac{\partial V_i^P(S^{'}, L_i^{'}(L_i, a_i^P, l_i^P), p_L^{'})}{\partial L_i} \\
\Rightarrow \frac{\partial V_i^P(S, L_i, p_L)}{\partial L_i} &= p_L \\
\Rightarrow \frac{\partial V_i^P(S, L_i, p_L)}{\partial L_i} &= \frac{\partial \pi(a_i^P, S)}{\partial a_i} - \beta \delta_i \frac{\partial V_i^P(S^{'}, L_i^{'}, p_L^{'})}{\partial S}.
\end{aligned} \tag{33}$$

We can then obtain the condition that governs the trajectories of extraction, recharge, and the price of water rights for an interior solution to exist:

$$\begin{aligned}
&\frac{\partial V_i^P(S, L_i, p_L)}{\partial L_i} = \beta \beta_{L,i} \frac{\partial V_i^P(S^{'}, L_i^{'}(L_i, a_i^P, l_i^P), p_L^{'})}{\partial L_i} \\
&\Rightarrow p_L = \beta \beta_{L,i} p_L^{'}
\end{aligned} \tag{34}$$

Then, under our simple case of spatial homogeneity, if we alter the equation of motion for each player's stock of permits so that they receive $\beta_{L,i}$ permits in the next period for each permit saved in the present, the regulator can achieve a socially optimal result by setting $\beta_{L,i}$ to be:

$$\begin{aligned}
\frac{1}{\beta\beta_{L,i}} - 1 &= \frac{1}{\beta}\left(1 - \frac{\frac{\partial \Pi(a^{SP},S)}{\partial S}}{\frac{\partial \Pi(a^{SP},S)}{\partial S} + \frac{1}{\delta}\frac{\partial \pi(a_i^{SP},S)}{\partial a_i}}\right) - 1 \\
\Rightarrow \frac{1}{\beta\beta_{L,i}} &= \frac{1}{\beta}\left(1 - \frac{\frac{\partial \Pi(a^{SP},S)}{\partial S}}{\frac{\partial \Pi(a^{SP},S)}{\partial S} + \frac{1}{\delta}\frac{\partial \pi(a_i^{SP},S)}{\partial a_i}}\right) \\
\Rightarrow \frac{1}{\beta_{L,i}} &= 1 - \frac{\frac{\partial \Pi(a^{SP},S)}{\partial S}}{\frac{\partial \Pi(a^{SP},S)}{\partial S} + \frac{1}{\delta}\frac{\partial \pi(a_i^{SP},S)}{\partial a_i}} \\
\Rightarrow \frac{1}{\beta_{L,i}} &= \frac{\frac{\partial \Pi(a^{SP},S)}{\partial S} + \frac{1}{\delta}\frac{\partial \pi(a_i^{SP},S)}{\partial a_i} - \frac{\partial \Pi(a^{SP},S)}{\partial S}}{\frac{\partial \Pi(a^{SP},S)}{\partial S} + \frac{1}{\delta}\frac{\partial \pi(a_i^{SP},S)}{\partial a_i}} \\
\Rightarrow \frac{1}{\beta_{L,i}} &= \frac{\frac{1}{\delta}\frac{\partial \pi(a_i^{SP},S)}{\partial a_i}}{\frac{\partial \Pi(a^{SP},S)}{\partial S} + \frac{1}{\delta}\frac{\partial \pi(a_i^{SP},S)}{\partial a_i}} \\
\Rightarrow \frac{1}{\beta_{L,i}} &= \frac{\frac{\partial \pi(a_i^{SP},S)}{\partial a_i}}{\bar{\delta}\frac{\partial \Pi(a^{SP},S)}{\partial S} + \frac{\partial \pi(a_i^{SP},S)}{\partial a_i}} \\
\Rightarrow \frac{1}{\beta_{L,i}} &= \frac{\frac{\partial \pi(a_i^{SP},S)}{\partial a_i}}{\bar{\delta}\frac{\partial \Pi(a^{SP},S)}{\partial S} + \frac{\partial \pi(a_i^{SP},S)}{\partial a_i}} \\
\Rightarrow \beta_{L,i} &= \frac{\bar{\delta}\frac{\partial \Pi(a^{SP},S)}{\partial S} + \frac{\partial \pi(a_i^{SP},S)}{\partial a_i}}{\frac{\partial \pi(a_i^{SP},S)}{\partial a_i}} \\
\Rightarrow \beta_{L,i} &= 1 + \underbrace{\bar{\delta}\frac{\frac{\partial \Pi(a^{SP},S)}{\partial S}}{\frac{\partial \pi(a_i^{SP},S)}{\partial a_i}}}_{\geq 0} \geq 1.
\end{aligned} \tag{35}$$

Then in the case when present period payoffs are increasing in current groundwater stock, to counteract the price of permits rising faster than the social value of groundwater stock, the return $\beta_{L,i}$ on saved permits should be greater than or equal to one. In the case when there are no present period stock effects (i.e., $\frac{\partial \Pi(a^{SP},S)}{\partial S} = 0$), we see that $\beta_{L,i} = 1$. We see that the relative profitability of players also plays a role in determining the value of $\beta_{L,i}$. When extraction levels are relatively low (and thus stock effects become minor) and marginal profits are relatively higher, $\beta_{L,i}$ approaches 1. We can envision this perhaps as a drought scenario, in which only the most profitable acreage is planted, and relatively less total water is extracted. Then the intertemporal trading ratio $\beta_{L,i}$ reflects the more profitable current conditions through a relatively lower return on savings. In the opposite scenario when stock is higher and extraction is higher, potentially less profitable land is planted and marginal profits fall. Then the intertemporal ratio $\beta_{L,i}$ should reflect the fact that stock is currently less scarce but will decline in the future if current extraction is higher, by promising a higher return on savings, since the value of stock will not change by as much as the price of permits in the next period.

# 5 Data

## 5.1 Empirical Setting

Our dataset covers the years 2004-2013. The Beaumont Basin was adjudicated when the basin's four municipal water companies formed the San Timeoto Watershed Management Authority and brought suit in January 2001 with a settlement reached and property rights instituted in February 2004 (Court, 2004; Landridge et al., 2016). Thus, our period of analysis begins in 2004, and covers the years following the adjudication of property rights in the Beaumont Basin. We end our period of analysis in 2013 because the basin had its safe yield revised and property rights adjusted downward for overlying users in 2015. Since we do not know how well this 2015 change was anticipated, we end our dataset in 2013 to avoid capturing any anticipation of this change.

We use data on all the groundwater users in the Beaumont Basin during 2004-2013 to estimate our open access dynamic game. The Beaumont Basin provides groundwater to a mix of farmers, recreational users (golf courses, retirement homes, and housing developments), and municipalities in the area, including the cities of Banning, Beaumont, Calimesa, and Yucaipa. Groundwater in the basin was appropriated, or sold for use outside of the land on which it was extracted, by four municipal water companies: Beaumont-Cherry Valley Water District, City of Banning, South Mesa Water Company, and Yucaipa Valley Water District. Appropriators may own wells both inside and outside the Beaumont Basin. Our data set includes two golf courses (California Oak Valley Golf and Resort LLC; and Southern California Professional Golf Association (PGA)), one housing development (Oak Valley Partners LLP), and two retirement homes (Plantation on the Lake; and Sharondale Mesa Owners Association). All recreational users (golf courses, retirement homes, and housing developments) are based inside Beaumont Basin. Our data set includes two farmers inside Beaumont Basin and four farmers outside Beaumont Basin. We include farmers based outside Beaumont Basin in addition to farmers based inside of Beaumont Basin because the actions of farmers outside Beaumont Basin help to determine depth to groundwater at wells outside the Beaumont Basin for appropriators with wells both inside and outside the Beaumont Basin through nearby extraction variables. Farmers outside Beaumont Basin may also be of interest in our study due to any spillover benefits they receive through the effect of the property rights system on extraction at wells outside the Beaumont Basin by appropriators with wells both inside and outside the Beaumont Basin.

A key feature that we make use of in our estimation procedure is the structure and rules imposed on groundwater pumping rights, including how they were allocated to different users, and how each player's stock evolved based on their action choices. This provides structure for the state transition densities for each player's extraction rights. For each groundwater user, the property rights specify the maximum amount that could be extracted in the current year without potentially facing penalties requiring payments for replenishment costs (Court, 2004; Beaumont Basin Watermaster, 2018).

Overlying users were allocated recurring annual pumping rights that correlated to their land ownership and use of groundwater on their land. Property rights for overlying users were shares of the estimated sustainable yield, and were essentially allocated as the same amount each year. The annual property right allocation for each overlying user was therefore constant over time. Overlying users must not exceed five times their annual allocation in any five consecutive years (Court, 2004; Beaumont Basin Watermaster, 2018). In our data during our period analysis (2004-2013), none of the overlying users exceeded their one-year allocation in any year, and all of the overlying users always extracted strictly below their five-year cap of five times their annual allocation.

Each of the four appropriators in our dataset were granted quantified initial allocations of pumping rights that phased in over ten years. This ten-year allocation of rights was based on shares derived from their historical extraction and a 'surplus' total allocation. The annual allocation for each year of this ten-year allocation was part of the judgment (Court, 2004), and was therefore known by appropriators by time the property rights regime began at the beginning of 2004. Appropriators were also promised shares of any unused overlying water rights at a five year lag. Both of these appropriator allocations were determined using their relative levels of historical pumping at wells inside the Beaumont Basin in the years prior to the adjudication. Appropriators were allowed to import water and use it for artificial recharge of the Beaumont Basin, and were promised the full right to the quantity of water recharged. Rights were allowed to be traded and stored over time at a one-to-one ratio. Appropriators must not exceed five years of allocations in any five consecutive years; if they do, they must provide the Watermaster with sufficient funds to replace any amount of overproduction that may have occurred over a five-year consecutive period (Court, 2004; Beaumont Basin Watermaster, 2018). In our data during our period of analysis (2004-2013), none of the appropriators ever exceeded their five-year cap, although some appropriators exceeded their annual allocation in some years, and all of the appropriators always extracted strictly below their five-year property rights allocation.

Property rights trading between players was limited in practice, likely reflecting high transaction costs and the relatively small number of agents.

Overlying players do not trade parts of their annual allocation, but instead either (1) sell the perpetual right to this allocation with their land, or (2) trade it to an appropriator in return for access to water district service (Watermaster, 2012). The former happened only once in the data in our sample period (2004-2013): Sunny-Cal Egg Co. sold the perpetual right to their allocation with their land in 2006. No transfers of water rights from overlyers to appropriators took place in the data during our sample period (Beaumont Basin Watermaster, 2018).

To trade their water rights, appropriators were allowed to either (1) negotiate their own deal; (2) ask the Watermaster to conduct a sealed bid auction, or (3) sell their pumping rights to the watermaster at a rate based on the price of recharge, with the rights and funding for their purchase allocated among the remaining three appropriators based on their historical pumping shares (Watermaster, 2006). In practice, appropriators generally used recharge instead to adjust their water rights levels. Among the appropriators in our data during our sample period (2004-2013), BCVWD purchased rights from South Mesa Water Company 4 times (2007-2009, 2011) for a total of 11,000 acre-feet; and City of Banning purchased rights from South Mesa Water Company once in 2007 for 1500 acre-feet (Court, 2004; Beaumont Basin Watermaster, 2018).

For artificial recharge, Beaumont-Cherry Valley Water District owns the only recharge facility that has operated in Beaumont; the recharge facility became operational in 2006. The City of Banning began purchasing imported water for recharge at the Beaumont-Cherry Valley Water District facility in 2008. Neither of the other two appropriators have purchased water for artificial charge (Beaumont Basin Watermaster, 2020).

For SWP filtered water sales, only one appropriator had a filtration facility for treating imported water during our period of analysis (2004-2013): Yucaipa Valley Water District (San Gorgonio Pass Water Agency, 2008). We do not find any records of the other appropriators in our sample having such facilities; they would therefore be unable to make filtered sales.

### 5.2 Data Sources

For extraction data, we use a mix of data from the San Timoteo Watershed Management Authority, the San Gorgonio Pass Water Agency, and the Beaumont Basin Watermaster. Data on artificial recharge and net trading activities are from the Beaumont Basin Watermaster. Data on imported water sales are from the San Bernardino Valley Municipal Water District. Data on property rights are from the Beaumont Basin Watermaster annual reports.

For data on wells, we collect and construct a database of well characteristics and location for each owner in each year from detailed handwritten hard-copy historical records on well location, well characteristics such as the depth of the well, and the maximum extraction rate in gallons per minute from the California State Water Resources Control Board's Groundwater Recordation Program (California State Water Resources Control Board, 2021). We merge the handwritten hard-copy historical records wells location data from the Groundwater Recordation Program and a well completion report dataset from the California Department of Water Resources with the well's state well identification number to determine the location of each the wells, and then merge the resulting well characteristics and location data with reported data from the Beaumont Basin Watermaster and the San Timoteo Watershed Management Authority. We map our well locations data to data from the US Department of Agriculture (USDA) Web Soil Survey and calculate an average saturated hydraulic conductivity value for each owner's wells inside and outside the Beaumont Basin; these data are fixed over time.

For data on depth to groundwater, we use observations from the US Geological Survey (USGS) Historical observations dataset. We collapse our data into annual depth to groundwater near each owner's wells inside or outside the boundaries of the Beaumont Basin. In order to do this we average over the nearest neighbor monitoring observations for each well owned by an owner either inside or outside the basin. Thus each well owned by one of our groundwater extractors has a corresponding monitoring well in the dataset. We interpolate for missing years in our depth to groundwater data by using the inverse-distance weighted annual change in depth to groundwater at other nearby wells with available data.

Data on prices for untreated water are from the Metropolitan Water District, a large State Water Project Contractor in Southern California. We take equivalent use price and delivery data from the State Water Project's annual Bulletin 132 report.

Prices for relevant agricultural crops (apples, cherries, grapes, alfalfa, olives, and strawberries) are from the USDA National Agricultural Statistics Service (NASS) Monthly Agricultural Prices survey. We use end-of-March surveys in each year to map a price. We choose this month to correspond to the price data available at the time of the planting decision for farmers. Electricity prices are from the Southern California Edison on annual end-use price by sector. For real GDP per capita, we use statewide annual data from the US BEA, with chained 1997 prices.

We make use of precipitation and daily maximum temperature data from the PRISM Climate Group (PRISM Climate Group and Oregon State University, 2018). We use 4 km resolution data from the PRISM's historical dataset, and map it to the extraction wells in our dataset based on location. We then collapse our data into annual and growing season (April-October) averages across wells inside or outside the Beaumont Basin for each owner.

In our demand estimation, we use data on per household monthly residential water demand, fixed charge, variable price, and connection fee from the California/Nevada Water Rate Survey conducted by the American Water Works Association. This survey is conducted once every two years and covers a large sample of municipal water districts in California. We use data on household size and population by city and county from the California Department of Finance; data on median adjusted gross income by county from the California Franchise Tax Board; and data on the industrial average electricity price for California from the US Energy Information Administration (EIA).

Summary statistics for our data are presented in Tables A.1-A.4 in Appendix A.

# 6 Structural Econometric Model

## 6.1 Dynamic Game Among Groundwater Users

To take our theory model to data we estimate a structural model of the dynamic game played among groundwater extractors in the Beaumont Basin region in the period following the adjudication of property rights. The players include groundwater users with wells in the adjudicated basin area, groundwater users with wells lying outside the adjudicated basin area, and groundwater users with wells both inside and outside the adjudicated basin area. We assume that players act non-cooperatively and make decisions regarding extraction, recharge, imported water sales to customers, and well drilling in order to maximize the present discounted value of the entire stream of expected per-period payoffs.

Our dynamic game includes three types $j$ of groundwater users $i$ in our dynamic game: farmers $F$ who use the water to irrigate their crops, recreational users (golf courses, retirement homes, and housing developments) $R$ that use water for irrigated landscaping on their properties, and municipal water districts (appropriators) $A$ that sell water to residential customers. Municipal water districts may own wells both inside and outside the Beaumont Basin. All recreational users (golf courses, retirement homes, and housing developments) are based inside Beaumont Basin. We include farmers based outside Beaumont Basin in addition to farmers based inside of Beaumont Basin because the actions of farmers outside Beaumont Basin help to determine depth to groundwater at wells outside the Beaumont Basin for appropriators with wells both inside and outside the Beaumont Basin through nearby extraction variables. Farmers outside Beaumont Basin may also be of interest in our study due to any spillover benefits they receive through the effect of the property rights system on extraction at wells outside the Beaumont Basin by appropriators with wells both inside and outside the Beaumont Basin.

Each player $i$ chooses a vector $a_i$ of actions each period. For appropriators (municipal water districts) $A$, the actions $a_i$ to be chosen include extraction at wells inside the adjudicated basin, extraction at wells outside the adjudicated basin, artificial recharge, imported water sold to customers, and wells drilled inside and outside of the adjudicated basin. For farmers $F$, who could not augment their water rights through recharge and whose wells are all located in one area (i.e., either all inside Beaumont Basin or all outside Beaumont Basin), the actions $a_i$ to be chosen include extraction and wells drilled. For recreational users (golf courses, retirement homes, and housing developments) $R$, who could not augment their water rights through recharge, did not drill any wells during our period of analysis (2004-2013), and whose wells are all located in one area (i.e., either all inside Beaumont Basin or all outside Beaumont Basin), the action $a_i$ to be chosen is extraction.

The per-period payoffs $\pi_{ij}(\cdot)$ for each player $i$ depend on the player's type (or use) $j$, where $j$ is either farming, recreational, or municipal; the player's action $a_i$; and the publicly observable state variables $x_i$. The state variables include: the depth to groundwater $S$, a measure of stock, at each well in the game; the water rights $L$ currently owned by each player; and the vector $Z$ of weather, economic, and price variables that help determine payoffs and state transitions. We impose structure from the rules and regulations governing the property rights system which determines the equation of motion for the stock of extraction rights owned by each player. Since property rights trading was limited during our period of analysis (2004-2013) (Beaumont Basin Watermaster, 2018), we take the few trades as given and exogenous, assume rational expectations, and treat the trades as part of the state vector $Z$.

For farmers $F$, the payoffs $\pi_{iF}(\cdot)$ are the agricultural profits from groundwater extraction used for farming, and are given by:

$$\pi_{iF}(a_i, S, Z) = R_F(a_i, Z) - C^E(a_i, S) - C^W(a_i, S), \tag{36}$$

where $R_F(\cdot)$ is the agricultural revenue from groundwater extraction used for farming, $C^E(\cdot)$ is the cost of extraction, and $C^W(\cdot)$ is the cost of well drilling. For farmers we model marginal revenues as a flexible, linear function of state variables related to weather conditions that could affect yields, and economic variables that could impact demand and prices for their products.

For recreational users (golf courses, retirement homes, and housing developments) $R$, the payoffs $\pi_{iF}(\cdot)$ are the profits from groundwater extraction used in landscaping, and are given by:

$$\pi_{iR}(a_i, S, Z) = R_R(a_i, Z) - C^E(a_i, S), \tag{37}$$

where $R_R(\cdot)$ is the revenue from groundwater extraction used in landscaping. We use separate linear functions to represent marginal revenues for golf courses, retirement homes, and housing developments, respectively. Since these players do not drill wells, there is no well drilling cost function included in the payoff.

For appropriators (municipal water districts) $A$, the action vector $a_i$ has six elements: extraction at wells inside the adjudicated basin, $e_i^I$; extraction at wells outside the adjudicated basin, $e_i^O$; imported water used for recharge, $R_i$; imported water used for sales to customers, $F_i$; wells drilled inside the adjudicated basin, $w_i^I$; and wells drilled outside the adjudicated basin, $w_i^O$. Their payoffs are given by:

$$\pi_{iA}(a_i, S, L, Z) = R_A(a_i, Z) + w_{CS} CS_i(a_i, Z) + w_{CS2}\left[CS_i(a_i, Z)\right]^2 + g(a_i, L, Z) - C^E(a_i, S) - C^W(a_i, S), \tag{38}$$

where $R_A(a_i, Z)$ is the revenue from water sales, $CS_i(a_i, Z)$ is consumer surplus, and $g(a_i, L, Z)$ are the net benefits from holding property rights and importing water in the given period. The revenue from water sales, $R_A(a_i, Z)$ , is given by:

$$R_A(a_i, Z) = P_i(W(a_i), Z)W(a_i), \tag{39}$$

where $P_i(\cdot)$ is the inverse water demand and where the total water sales $W(a_i)$ are given by:

$$W(a_i) = e_i^I + e_i^O + F_i. \tag{40}$$

To determine water sale revenues $R_A(a_i, Z)$ and consumer surplus $CS_i(a_i, Z)$, we use a model of residential water demand for a given level of total water sales by the appropriator estimated in Sears et al. (2023c).[4]

We allow municipal water districts to care about both consumer surplus $CS_i(a_i, Z)$ and the profits from water sales, where the profits from water sales include all other terms in their payoff, including water sale revenues $R_A(a_i, Z)$, net benefits $g(a_i, L, Z)$ from holding property rights and importing water, extraction costs $C^E(a_i, S)$, and well drilling costs $C^E(a_i, S)$. This structure reflects the multiple objectives that water districts may have as municipally owned firms (Peltzman, 1971; Baron and

[4]Our residential water demand function is not a new contribution from this paper, and so our discussion of our modeling choices and results are limited in the main text. In Appendix Section C.1 we include our description of this model from Sears et al. (2023c).

Myerson, 1983; Timmins, 2002; Sears et al., 2023c). In particular, we allow the per-payoffs for municipal water districts to be a weighted quadratic function of consumer surplus $CS_i(a_i, Z)$, and the profits from water sales. We allow consumer surplus to enter the function quadratically to allow for the possibility that the appropriator may value benefits to their customers, but at a diminishing rate. The appropriator weights $w_{CS}$ and $w_{CS2}$ on consumer surplus and on consumer surplus squared are among the structural parameters we estimate. This is the same approach employed in Sears et al. (2023c).

Appropriators also derive benefits from importing water and holding property rights in a given period, which is captured through the function $g(a_i, L, Z)$. Appropriators may wish to hold property rights in order to expand service and promote development, which requires the company to have access to sufficient supplies of water.[5] In addition, municipalities must publish detailed sources of water every five years as part of the Urban Water Management Plan Act in California (California Legal Code, 1983). We model the value of property rights as a function of the number of property rights, prior to and after trades and import decisions, as well as extraction lift-cost difference between wells inside and outside the Beaumont basin. We also model benefits derived from imported water. For water that is filtered and sold directly to customers, these benefits can be understood as outside of any producer profits from water sales. For water used for artificial recharge this can be seen as the full benefit gained net of any additional costs of recharge outside of the price of purchasing imported water. We allow these benefits to depend in both cases on the state of the groundwater stock in Beaumont. For artificial recharge we also allow benefits to depend on distance to the recharge facility used in Beaumont. The cost of imported water is determined by the price charged by Metropolitan Water District, a regional water contractor, for untreated water. This is a price charged to water districts like those included in our model.

The extraction cost function $C_j(a_i, x_i)$ includes a common component and player-type specific quadratic effects. The quadratic component represents adjustment costs necessary to ramp up extraction and transmission of water for each player. Following Rogers and Alam (2006), Sears et al. (2019) and Sears et al. (2023c), we model the common component of the cost of water extraction as a function of the price of electricity $P_E$ (in dollars per kwh), depth to groundwater $d_i$ (in feet), and the amount of electricity $E_L = 1.551$ (in kwh) required to lift one acre-foot of water one foot. The extraction cost function $C_j(a_i, x_i)$ is given by:

$$C_j(a_i, x_i) = P_E E_L d_i a_i + c_2^j a_i^2, \tag{41}$$

where the cost parameters $c_2^j$ in the quadratic component for each type $j$ are among the structural parameters we estimate. We estimate a separate cost function for farmers and a separate cost function

[5] California's Environmental Quality Act requires municipal water companies to conduct an environmental impact report disclosing the likely source of water used to meet the needs of the proposed large developments, as well as whether it is likely to be sufficient to meet the ultimate level of development, and the level of certainty over the availability of long term sources of water (California Legal Code, 1970).

for recreational users, both of whose wells are only located on their property. As water districts have wells both inside and outside the Beaumont Basin, we calculate one cost function for appropriator extraction inside the Beaumont Basin, and a separate cost function for appropriator extraction outside the Beaumont Basin.

We model the costs of well drilling, $C^W(a_i, S)$, as a linear function of the current depth to groundwater for the player at their wells. This represents the fact that deeper wells need to be drilled by players facing lower water table levels. Well drilling in our dynamic game is limited to appropriators and farmers since we do not observe well drilling by recreational users (golf courses, retirement homes, and housing developments) in our data.

The equilibrium concept we use for our dynamic game is a Markov perfect equilibrium (MPE). Vespa (2020) provides experimental evidence that behavior in a dynamic common pool game can be rationalized with equilibrium Markov strategies that do not condition on history. In a Markov perfect equilibrium, each player's strategy $\sigma_i(x)$ is a best-response function conditional on their expectations about the future state implied by the current state, the behavior of all other players, and the transition dynamics of the system.

We assume the full state vector $x = \{x_i\}$ is common knowledge. The state variables $x$ affect our game through the state transition densities and the player policy functions $\sigma_i(x)$. For the transition density for depth to groundwater, we assume that depth to groundwater is stochastic and follows a first-order controlled Markov process: the distribution of depth to groundwater next period depends on the depth to groundwater this period, the value of the other state variables this period, and the groundwater extraction action variables this period. To simplify our analysis we model the state transitions of our remaining state variables as following rational expectations.[6]

Each player $i$ of type $j$ chooses its action $a_i$ to maximize the expected present discounted value of its entire stream of per-period payoffs, given the state variables $x$ and the strategies $\sigma_{-i}$ of the other players, yielding the following value function:

$$V_{ij}(S, L, Z) = \max_{a_i} \left[ \pi_{ij}(a_i, S, L, Z) + \beta E[V_{ij}(S^{'}, L^{'}, Z^{'}) | a_i, \sigma_{-i}, S, L, Z] \right], \tag{42}$$

where $\beta$ is the discount factor. Each player takes into account their expectations about the evolution of the full vector of state variables in their decision-making process and chooses a strategy over the full set of states that optimizes the expected present discounted value of per-period profits.

## 6.2 Econometric Estimation

To estimate the parameters for the dynamic game, we use the two-step forward simulation-based approach developed by Bajari et al. (2007). In the first step of our estimation strategy, we estimate

[6] In our structural econometric model of the dynamic game under open access prior to the institution of property rights in (Sears et al., 2023c), we make a similar rational expectations assumption, conduct several robustness checks that relax the rational expectations assumption, and find that our results are generally robust to whether we assume rational expectations for the remaining state variables.

residential water demand, policy functions $\sigma_i(x)$ for each player type, and state transition densities for depth to groundwater. In the second step, we forward simulate estimates of the value function at a set of states under policies and transition functions estimated in the first stage and find parameters that minimize any profitable deviations from the optimal strategy as given by the policy functions estimated in the first step. The estimated parameters are then consistent with Markov perfect equilibrium behavior in a game in which player expectations are consistent with the observed first-stage state transitions and policy functions (Bajari et al., 2007).

Finding a single equilibrium is computationally costly even for problems with a simple structure. In more complex problems – as in the case of our dynamic game between groundwater users, where many agents are involved – the computational burden is even more important, particularly if there may be multiple equilibria. We apply the method proposed by Bajari et al. (2007) for recovering the dynamic parameters of the payoff function without having to compute any single equilibrium. The crucial mathematical assumption to be able to estimate the parameters in the payoff function is that, even when multiple equilibria are possible, the same equilibrium is always played.

### 6.3 Policy Functions

To determine the optimal action choices for players in each period of the model we estimate separate policy functions that correlate actions to states for the extraction, recharge, filtered imported water sales, and appropriator well drilling decisions of each type of player in our game. Policy functions are parametric functions relating these decisions to the state variables in our dataset. We choose state variables based on their ability to minimize simulation error, or the difference between our simulated actions and those observed in the data. Our functions then are valid over the state space in our observed dataset, but not for states outside of this space.

We separately model the total extraction, and the share of extraction done at wells inside the Beaumont Basin decisions of appropriator players. These results are found in Table 1. Likewise, we estimate separate models for farmer players extraction at wells inside and outside the Beaumont Basin. It is important to separately model these decisions due to the regulatory differences in how extraction is treated at wells inside and outside the Beaumont Basin. For recreational users (golf courses, retirement homes, and housing developments), our sample only includes extractors inside of Beaumont, so we only estimate a single model. These results are found in Table 2.

For water import decisions, we split this decision into two separate models, one for water used for artificial recharge, and another for water that was filtered and sold directly to customers. Since the use of this imported water determines their impact on the player's property rights, and profits, it is important to model these decisions separately.

For the recharge policy function, we model artificial recharge as an option for only two appropriators in the game during our period of analysis (2004-2013): Beaumont-Cherry Valley Water District, which owns the only recharge facility that has operated in Beaumont; and the City of Banning, which began purchasing imported water for recharge at the Beaumont-Cherry Valley Water District facility in 2008. Neither of the other two appropriators in the model have purchased water for artificial recharge (Beaumont Basin Watermaster, 2020).

For the SWP filtered sales policy function, we model SWP filtered sales as an option for only the one appropriator that had a filtration facility for treating imported water during our period of analysis (2004-2013): Yucaipa Valley Water District (San Gorgonio Pass Water Agency, 2008). We do not find any records of the other appropriators in our sample having such facilities; they would therefore be unable to make filtered sales.

The results for our policy functions for artificial recharge and SWP filtered sales are found in Table 3.

For well drilling, we estimate a binary outcome model using the sample of all players in our dynamic game. Results for this model are found in Table 3. We model this drilling decision as separate for wells inside and outside the Beaumont Basin for appropriator players.[7] We determine the number of new wells in our simulation using a random normal draw from a distribution based on the well drilling decisions in our dataset censored below at 1 well drilled.

We represent the share of each decision determined outside the model using the root-mean squared prediction error from this adjusted predicted value and taking a random normal draw.

## 6.4 State Transition Densities

We separately estimate state transition densities for depth to groundwater for each type of player and for wells located inside and outside of the Beaumont Basin. Wells for appropriators and other players differ in important respects including the depth of the well, as well as the rate at which water is extracted. In addition the hydrology of the Beaumont Basin differs from that of the surrounding basins. For these reasons it is important to model depth to groundwater separately based on player ground and basin. For the transition densities for depth to groundwater for each type of player, we estimate models that include lagged depth to groundwater, extraction by the player, extraction by other players, physical features of the area surrounding the player's wells, economic variables, weather conditions, and variables related to artificial recharge in the area; and we let the data tell us what the transition density is. We only use variables that prove significant in our state transition regressions in the second stage simulation. We adjust our constant to equate predicted values with values in the data. We account for unobserved factors that affect state transitions using the root-mean squared prediction error from this adjusted predicted value and taking a random normal draw. Our transition densities for depth to groundwater are presented in Table 4.

[7]For our base-case specification, we estimate the well drilling policy functions using all observations, and allow for any player to drill in the simulation. As a robustness check, in an alternative specification of the well drilling policy function, we only allow drilling by appropriators and farmers, as appropriators and farmers are the only player types to drill in the data, and include a dummy variable for appropriator as a regressor. This allows us to determine whether our results are robust to our methodological choice of allowing all players to drill wells during the game. As seen in the results of our alternative specification in Appendix B, our results are robust to the specification of the well drilling policy function.

For crop prices, well characteristics, and weather, we assume rational expectations by players in the base case model. We also assume that none of our players can influence crop prices, well characteristics, or weather through their behavior. This is a reasonable assumption given the relatively small size of operations in the Beaumont Basin relative to other nearby population centers and agricultural operations.[8]

### 6.5 Estimating the Structural Parameters

For the second step of our estimation strategy, following Bajari et al. (2007), we forward simulate the value functions for each player in the open access period, and we estimate our structural parameters $\theta$ by minimizing the sum of profitable deviations from the optimal strategy as estimated by our policy functions. The structural parameters $\theta$ we estimate include revenue and cost parameters for farmers, recreational users, and appropriators; and parameters governing the relative weights that appropriators place on consumer surplus versus the profits from water sales. We set the discount factor $\beta$ to 0.9. To generate deviations from the optimal strategy, we perturb our policy functions using random draws to increase and decrease the level of the policy function; these perturbations are normally distributed with a standard deviation equal to the standard deviation of the relevant player-type extraction decision in the data. To ensure that we find a global minimum, we iterate over multiple initial guesses, searching over the set of combinations of parameter values, in order to find the parameters that minimize the sum of profitable deviations.

Identification of the parameters in the marginal revenue and costs of extraction for each player type (farmers, recreational users, appropriators) come from variation in extraction and state variables across players and across years for each player type. Identification of the parameters in the other net benefits and costs come from variation in action and state variables across players and across years. Identification of the weights in the per-period payoff on consumer surplus come from variation in water sale profits and consumer surplus across appropriators and across years. Water sale profits depend on extraction costs, and well drilling costs, whose parameters are indentified from variation in extraction, well drilling, and state variables across players and across years for each player type; and on water sale revenues and the net benefits from holding property rights and importing water, whose parameters are identified from variation in extraction, property rights, water imports, and state variables across appropriators and across years. Consumer surplus is calculated by integrating the area under the inverse residential water demand above price, using the parameters in the residential water demand function estimated in the first stage. Variation in consumer surplus comes from variation in extraction, the number of households, and the average household size across water districts and across years.

[8] In our structural econometric model of the dynamic game under open access prior to the institution of property rights in (Sears et al., 2023c), we make a similar rational expectations assumption, conduct several robustness checks that relax the rational expectations assumption, and find that our results are generally robust to whether we assume rational expectations for the remaining state variables.

# 7 Results

## 7.1 Structural Parameters

We now examine our structural parameter estimates from the dynamic game under the property right regime.

Table 5 reports our estimated revenue parameters. The parameters for farmer marginal revenue show that higher precipitation increases the profitability of groundwater. We also find that farmers in the Beaumont Basin earned significantly higher marginal revenues from groundwater extraction than their counterparts outside of the basin.

For recreational users (golf courses, retirement homes, and housing developments), we find that the marginal revenue for golf courses is higher during periods of higher economic productivity. On average, the marginal revenue from groundwater extraction is lower for golf courses than for retirement homes and housing developments. In general, the revenues for recreational users (golf courses, retirement homes, and housing developments) are not as directly related to their groundwater use as they are for farmers.

For appropriators, we find marginal revenue is lower during periods in which more water is required to landscape or irrigate due to climate (as captured by higher evapotranspiration), likely via a higher cost of conservation activities. In contrast to our findings in Sears et al. (2023c) that appropriators over-weighted consumer surplus during the open access period, on average we find that, after the institution of quantified property rights, the weight that appropriators placed on consumer surplus relative to producer profits is increasing in consumer surplus, but lower on average than what we found under open access. In our base-case specification, we find that, after the institution of quantified property rights, appropriators tended to weight consumer surplus about 20 percent lower than producer profits; we find in our alternative specification in Appendix B that, after the institution of quantified property rights, appropriators placed roughly equal weight on consumer surplus and producer profits. So the advent of property rights either eliminated or reversed the direction of the consumer surplus weighting problem.

Turning to cost functions in Table 6, we find that costs from extraction are convex in extraction per well for farmers, but not for appropriators. For farmers, who have a more limited set of wells (with each farmer owneing 2.54 wells on average, as seen in Table A.2) and therefore may be more capacity constrained, increasing pumping involves using their limited set of wells less efficiently, which could increase costs. In contrast, appropriators have several wells both inside and outside Beaumont Basin (with each appropriator owning 27.93 wells on average, as seen in Table A.1), and therefore be less capacity constrained and better able to use their larger set of wells more efficiently, focus on extracting from the least-cost and most efficient wells, and substitute across wells when extracting from one well is cheaper than extracting from another.[9] For the cost of well drilling, unsurprisingly

[9]In their analysis of spatial externalities in California, for example, Sears et al. (2023a) find evidence that groundwater users cluster their pumping at wells where extraction is cheapest, and substitute extraction across wells when extracting

we find that costs increase in drilling depth. For a 200 ft deep well the implied cost is just under \$92,000. As commercial wells in California cost \$50,000 to \$100,000 for the drilling and pump alone, and not including the additional costs for a new well of electrical wiring, a pressure storage tank, and a permit ((CVFPB, 2020), our results for well drilling costs seem reasonable.

The per-period payoff for groundwater users also includes terms that account for the marginal value of property rights. For overlying users inside Beaumont Basin (farmers inside Beaumont Basin and recreational users), the per-period payoff includes a term for water extraction divided by the overlying user's property rights allocation net of trades. The higher the ratio of water extraction to the property rights allocation net of trades, the more binding (and scarce) the property rights, and therefore the higher their shadow price should be. We therefore expect a negative coefficient on this ratio, so that the total average effect of property rights is positive. Similarly, for appropriators, the per-period payoff includes a term for water extraction inside Beaumont Basin divided by the appropriator's property rights net of recharge. The higher the ratio of water extraction inside Beaumont Basin to the property rights net of recharge, the more binding (and scarce) the property rights, and therefore the higher their shadow price should be. We therefore expect a negative coefficient on this ratio, so that the total average effect of property rights is positive. Our results found in Table 7, show that, for appropriators, the total average effect of an additional property right held through the year is a value of roughly \$0.37 per acre-foot of rights each year for appropriators, although the effect was not significant. For overlyers, on average holding property rights created about \$2 per acre-foot of rights each year, although the effect was not significant. This result illustrates that the value of generating property rights is accrued in the period in which they are gained for appropriators, while perhaps being more durable for farmers and other overlyers.

The per-period payoff for approriators also includes terms that account for the value of imported value. As seen in Table 7, we find that importing water created significantly larger values than property rights did (per acre-foot) in the initial year in which the water was brought in, and moreover that the value of imported water is statistically significant. Recharge created around \$417 dollars per acre-foot, while filtered sales created around \$391. The difference between these, \$26, is likely due to the additional impact that recharge has on water table levels in the basin, which is captured by the appropriator and the corresponding impact on costs of extraction in the future, as well as the immediate impact on property rights. We find that appropriators that were more distant from the recharge facility valued the benefits of imported recharge more than those with wells located closer to the recharge facility.

## 7.2 Welfare

We use our structural parameters to examine the magnitude and distribution of welfare generated from groundwater extraction under open access. Table 9 presents the average annual welfare, consumer

from one well is cheaper than extracting from another.

surplus, and profits.

We find that average annual welfare for appropriators is around $31 million annually, which is close to what we found for annual average welfare for appropriators after the institution of property rights (roughly $30 million) in Sears et al. (2023c). Appropriators were generally not profitable, however, meaning that their positive welfare was entirely reliant on the consumer surplus they generated for customers as well as the value of imported water they brought in during the time period.

We calculate average annual social welfare from groundwater in Table 10. Social welfare is equal to the sum of producer surplus and consumer surplus. Producer surplus is equal to the profits from groundwater extraction summed over all players, plus the value of holding property rights for appropriators. Consumer surplus is the consumer surplus faced by each appropriator, and is not weighted by parameters in the payoff function of the appropriator. Importing water accounts for around $1.9 million per year in additional payoffs. Thus this helps to partly explain the difference in welfare relative to our results for just welfare related to groundwater extraction after the institution of property rights in Sears et al. (2023c).

### 7.3 Model Validation

To assess the goodness of fit of our structural econometric model, we compare the action variables, state variables, and welfare predicted by our model over the sample period (2004-2013) with their actual values in the data. We call our model simulations of the sample period (2004-2013) the 'Base scenario'.

We first compare the action and state variables predicted by our model over the sample period (2004-2013) with the actual values in the data. Table 8 shows the average model simulated values of these variables, as well as the averages in the actual data, as well as the percentage differences between the two by type of player and basin location. We find generally that differences are small (less than 5 percent), except in the case of a smaller group of overlyer players with relatively low welfare levels.

In Figures 1-2, we plot and compare actual and model predicted trajectories of mean extraction for each type of user from 2004-2013. In Figures 3-4, we plot and compare actual and model predicted trajectories of mean extraction for each type of user from 2004-2013. For a more granular view our simulated data, we plot and compare individual player action choices in the data with those predicted by our model over the sample period (2004-2013) in Figures A.1a-A.5e in the Appendix; and we also plot and compare the actual and model predicted state transitions for individual player depth to groundwater in Figures A.6a-A.9e in the Appendix. We find that the pattern over time in our simulated extraction trajectories generally matches well with the actual data. In the case of the two farmers in the Beaumont Basin in our dataset, we find that the upward bias in extraction generally comes from higher extraction by players in later years; however, both players follow a similar pattern to what we observe in the actual data. With respect to imported water, which is shown in Figure A.3, we find the levels and patterns are generally consistent across appropriator players, with a gradual upward trend in each variable.

We also compare actual welfare and model predicted welfare. In Table A.5 in the Appendix, we show, for each player and player type, the actual welfare generated based on the observed player actions and state variables, the model predicted welfare generated from 100 simulation runs of the open access period, and the difference between model predicted and actual welfare. We use significance stars next to the difference between model predicted and actual average annual welfare to denote the significance level of the difference between model predicted and actual average annual welfare. We find that for appropriators our model predicted welfare is about 10 percent higher than the value observed in the dataset, and statistically significant. Nevertheless, both the actual and model predicted average annual welfare for appropriators (roughly \$28 million annually and \$31 million annually, respectively) are close to what we found for annual average welfare for appropriators after the institution of property rights (roughly \$30 million) in Sears et al. (2023c).

For farmers, the differences between actual and model simulated payoffs are smaller in magnitude and differ in sign across player types and locations. For farmers in the Beaumont Basin, the model simulated welfare is somewhat lower than what we observe in the actual data. However, they are generally statistically insignificant. We incorporate any bias for players in our later analysis. For recreational users we find that our model tends to under-predict welfare, and produces negative estimates for welfare for some players.

The likely explanation for this upward bias in appropriators payoffs is the difference in consumer surplus generated under the model predicted behavior vs. the actual data. In Table A.7 in the Appendix, we find that model predicted consumer surplus was about \$3.2 million higher than what we find in the actual data, or about 10 percent. This is likely due to the higher extraction in the simulated data in later years by appropriator players compared to extraction in the actual data. This has an outsized impact on appropriator welfare's bias, due to the high weight placed upon consumer surplus by these players in their payoff functions.

Table A.7 in the Appendix compares the actual and model predicted average annual payoffs associated with holding property rights by appropriators. We find a difference of less than \$0.1 million annually between our model prediction and the actual data, and the difference is statistically significant.

In Table A.6, we show the difference between estimated profits using model simulated data and that using actual data. We find that this also contributed to the difference in welfare for appropriators. Here profits actually bias our results downward relative to the actual data. This is driven by higher water sale costs in the simulated data than in the actual data.

## 8 Counterfactual Simulations

We run eight separate short-run counterfactual simulations to illustrate the impact of imported water and property rights trading on the behavior of players, the evolution of the groundwater stock, and the welfare from water for each group of players. In order, we run counterfactual scenarios for: (1) no artificial recharge, (2) no filtered imported water sales, (3) no property rights trading, (4) no water imports, (5) no water imports or property rights trading, (6) equal initial property rights allocations for appropriators, (7) no property right to recharged water for appropriators, and (8) revised safe yield allocation for overlyers. These counterfactual scenarios represent important changes to the set of methods player had at their disposal to supplement their groundwater extraction, and their property rights, and the rules which governed the property rights system.

In analyzing the short-run effects of each counterfactual scenario, we assume that the counterfactual change we simulate is one that groundwater users do not anticipate, and that the counterfactual scenario does not change which equilibrium is played. Adapting the policy invariance assumption and approach of Benkard et al. (2019), we therefore assume that the policy functions (as functions of state variables), transition densities of unaffected state variables (as functions of lagged state and action variables), and structural parameters we estimate themselves do not change under the different counterfactual policy changes.

For each counterfactual policy scenario, we simulate the effects of the counterfactual policy change on groundwater extraction, well drilling, depth to groundwater, artificial recharge, imported water sales, and welfare. We compare the results of each of the counterfactual scenarios to the actual data and to the results of the Base scenario in the absence of any counterfactual change.

### 8.1 No Artificial Recharge Counterfactual

We first restrict players from importing water for use in artificial recharge. This constraint is binding for the two appropriators for which artificial recharge was an option in the actual data – Beaumont-Cherry Valley Water District and City of Banning. Recharge allowed players to both replenish the groundwater stock in the Beaumont Basin, and to offset the effect of extraction on their stock of accumulated property rights.

Table 11 compares the welfare for each player under this counterfactual with player welfare under the actual data, and player welfare under the Base scenario in the absence of any counterfactual change. When artificial recharge is no longer an option in the counterfactual, this impacts appropriator profits by eliminating the costs of artificial recharge. In particular, the appropriator profits for the two appropriators for which artificial recharge was an option in the actual data – Beaumont-Cherry Valley Water District and City of Banning – are significantly higher under the counterfactual when artificial recharge is no longer an option. The unit cost of imported recharge and imported water sales is the 'Retail price of untreated water', which is the price the appropriator pays for imported water sales, and which we also assume that the price or cost of recharge since imported water is used to conduct artificial recharge.

Table 12 compares the social welfare under this counterfactual with the social welfare under the actual data, and social welfare under the Base scenario in the absence of any counterfactual change. We find that appropriators earned slightly higher consumer surplus for their populations when artificial recharge is no longer an option. In all, social welfare is slightly higher when artificial recharge is no longer an option.

We compare mean actions and states under this counterfactual with mean actions and states in the actual data and mean actions and states under the Base scenario in Table 13. Here we find that in the absence of recharge, appropriators shifted their extraction slightly away from the Beaumont Basin. We also find that they raised their overall extraction slightly as well by increasing extraction outside of the Beaumont Basin. We find that removing imported water also caused the stock to diminish significantly in the Beaumont Basin. Although there was not a significant impact on the level of the stock for these players outside the Beaumont Basin, there was an effect on stock inside the basin for nearby farmers. Here, we see that stock was lower in our counterfactual, and that these players responded by significantly increasing their extraction. Thus, recharge helped to stabilize stock inside the Beaumont basin, and balance extraction for both appropriators and overlyers.

In Figures A.10- A.13, we show the evolution of counterfactual extraction and depth to groundwater by player type, alongside the actual values in our dataset. Our results show that changes in the extraction pattern were not apparent in the first few years of our sample when recharge was not present in the actual data either. In subsequent years, however, we see appropriator extraction stayed relatively high before tailing off significantly in the final years of our dataset. We see that extraction at wells outside the Beaumont Basin remained higher than in the actual data throughout the period. Combined this lead to significantly worse stock conditions inside the Beaumont Basin. In the long run this level of overdraft could have threatened the existence of the stock of the Basin. We also see when looking at farmers, that extraction levels would still have fallen inside the Beaumont Basin, but would have leveled off at a much higher volume, as farmers would have consumed more in the short run.

## 8.2 No Filtered Sales Counterfactual

We next restrict players from importing water for sales to customers. This constraint is binding for the one appropriator for which SWP filtered water sales was an option in the actual data Yucaipa Valley Water District. Sales of filtered imported water acted as a supplement to the groundwater supply, allowing players to extract less groundwater to meet their customers needs.

The player welfare results in Table 14 show that, when SWP filtered water sales is no longer an option in the counterfactual, this impacts appropriator profits by eliminating the costs of SWP filtered water sales. In particular, the appropriator profits for the one appropriator for which SWP filtered water sales was an option in the actual data Yucaipa Valley Water District – are significantly higher under the counterfactual when SWP filtered water sales is no longer an option. The unit cost of imported recharge and imported water sales is the 'Retail price of untreated water', which is the price the appropriator pays for imported water fsales, and which we also assume that the price or cost of recharge since imported water is used to conduct artificial recharge. As seen in Table 15, consumer surplus for Yucaipa Valley Water District declines when SWP filtered water sales is no longer an option. In all, social welfare actually increased significantly SWP filtered water sales is no longer an option.. We find that impacts on other players in the Beaumont basin and beyond were not uniform and were small in general.

When comparing mean actions and states under this counterfactual with mean actions and states in the actual data and mean actions and states under the Base scenario in Table 16, we find that in the absence of imported water sales, appropriators did indeed extract more. However this shift did not have a significant impact on stock in either basin, or for other players in the Beaumont basin. For farmers outside the Beaumont basin, where extraction by appropriators increased more, we find the stock was somewhat lower, although this did not have an impact on extraction. Thus, filtered sales helped to offset extraction in both locations by appropriators but may have lead to water prices that were cheaper than socially optimal.

As seen in the trajectories of counterfactual versus actual extraction and depth to groundwater by player type in Figures A.14- A.17, we see dramatic differences in extraction behavior by appropriators, with significantly more extraction inside the Beaumont Basin during the mid-2000s, followed by a shift outside the Beaumont Basin in later years. In Figures A.18-A.22, we show these trajectories by individual player. We see in Figures A.18-A.19 that these changes are driven by the lack of change in extraction over time by the only player in our dataset who uses outside water for direct sales. Thus while this allowed their extraction to diminish in the actual data, they maintained high levels of extraction in our counterfactual. This seems to have somewhat influenced extraction by other players, as these players maintained higher levels of extraction inside the Beaumont Basin in the late 2000s in our counterfactual, while diminishing their extraction outside the Basin.

## 8.3 No Property Rights Trading Counterfactual

We next restrict players from trading property rights amongst themselves. This impacts both appropriators and some overlyers directly. Trading allowed players to adjust their stock of water rights, and their limits on extraction in a given year.

When comparing the social welfare for each player under this counterfactual with player welfare under the actual data, and player welfare under the Base scenario in Table 18, we find that differences were generally small. Trades have 0 net effect on overall producer profits directly, since they have offsetting effects on buyers and sellers. We do see that benefits from imported water were slightly higher in the counterfactual, however this was offset by lower producer profits. Thus there was little impact on social welfare on the whole. We find that impacts on player welfare in Table 17 were generally insignificant as well.

WWhen comparing mean actions and states under this counterfactual with mean actions and states in the actual data and mean actions and states under the Base scenario in Table 19, we find that in the absence of trading, players who recharged imported water increased this recharge. As a result, they were able to extract at similar levels, and maintain broadly similar levels of property rights stock. For other players we find that extraction was generally similar to the baseline as well.

For appropriators, we find that extraction at wells inside the Beaumont Basin went down slightly, which in combination with the increased recharge led to slightly improved levels of stock for them, and the farmers with wells inside the Beaumont Basin. Thus, trading does seem to have allowed appropriators to more balance their extraction without having to rely as much on imported water. The evolution of counterfactual extraction and depth to groundwater by player type in Figures A.23-A.26 show a similar pattern, as extraction in the Beaumont Basin by appropriators in the late 2000s was somewhat higher in our counterfactual than in the actual data.

### 8.4 No Water Imports Counterfactual

We next restrict players from importing water for either filtered sale or artificial recharge. This impacts three of the appropriators in our model directly. This can be seen as an extended interruption in the supply of the State Water Project to this region.

As seen in Table 20, when artificial recharge and SWP filtered water sales are no longer an option in the counterfactual, this impacts appropriator profits by eliminating the costs of artificial recharge and SWP filtered water sales. In particular, the appropriator profits for the two appropriators for which artificial recharge was an option in the actual data – Beaumont-Cherry Valley Water District and City of Banning – and for the one appropriator for which SWP filtered water sales was an option in the actual data Yucaipa Valley Water District – are significantly higher under the counterfactual when artificial recharge and SWP filtered water sales is no longer an option. The unit cost of imported recharge and imported water sales is the 'Retail price of untreated water', which is the price the appropriator pays for imported water fsales, and which we also assume that the price or cost of recharge since imported water is used to conduct artificial recharge. As seen in Table 21, social welfare increased by about half a million dollars per year when these supplies were restricted. This represents potentially a short term phenomenon, in which the full benefits of supplementing the stock of groundwater in the Beaumont Basin were not realized during our simulation. This suggests that the short-term benefits did not justify the immediate costs of importing the water.

As seen in Table 22, we find that in the absence of imports, stock in the Beaumont Basin diminished, driving appropriators to extract more from outside the Basin, and farmers, who could not adjust the location of their extraction, to increase their overall extraction in response. In Figures A.27- A.30, we see strong evidence that extraction would have been significantly higher under our counterfactual than in the actual data, both inside and outside of the Beaumont Basin. This mirrors a combination of the results we found in our first two counterfactuals. Again we see the external effect of removing recharge on farmers inside the Beaumont basin, who again extracted significantly more water in the late 2000s. Looking at the stock effect for farmers outside of Beaumont, we see that stock rebounded in our actual data, but would not have in the counterfactual.

## 8.5 No Imports or Property Rights Trading Counterfactual

We next eliminate all water imports and all property rights trading. Thus, for appropriators this represents a scenario in which the initial allocation of property rights are the only source of water rights in Beaumont that are directly under the appropriator's control (these players still receive re-allocations of any unused water rights from overlyers). For all players, the stock of the Beaumont Basin is now not replenishable through artificial recharge. Since imports are no longer available, even for sale to customers, appropriators must now react to changes in the stock of groundwater in Beaumont through re-allocation of their extraction between basins. For overlyers, this is not possible, since these players' wells are all located on the land they own.

As seen in Table 23, when artificial recharge, SWP filtered water sales, and property rights trading are no longer an option in the counterfactual, this impacts appropriator profits by eliminating the costs of artificial recharge and SWP filtered water sales. In particular, the appropriator profits for the two appropriators for which artificial recharge was an option in the actual data – Beaumont-Cherry Valley Water District and City of Banning – and for the one appropriator for which SWP filtered water sales was an option in the actual data Yucaipa Valley Water District – are significantly higher under the counterfactual when artificial recharge, SWP filtered water sales, and property rights trading is no longer an option. The unit cost of imported recharge and imported water sales is the 'Retail price of untreated water', which is the price the appropriator pays for imported water fsales, and which we also assume that the price or cost of recharge since imported water is used to conduct artificial recharge.

As seen in Table 24, consumer surplus decreases by about two tenths of a million dollars per year when artificial recharge, SWP filtered water sales, and property rights trading is no longer an option. The loss of payoffs from imported water was more than offset by the reduction in costs of imports, reflected through higher producer surplus. Social welfare is significantly higher when artificial recharge, SWP filtered water sales, and property rights trading is no longer an option.

As seen in Table 25, appropriator extraction at wells inside the Beaumont Basin was slightly lower, but that depth to groundwater was substantially higher. This suggests that players lowered extraction in response to the diminishing stock in Beaumont. In response they substantially raised extraction at wells outside of Beaumont to make up for lower extraction in Beaumont and the loss of imported water used for sales to customers. Farmers in the Beaumont basin would have had significantly higher extraction, as they acted less dynamically when faced with the diminishing stock. In Figures A.31- A.34, we see that extraction was notably higher outside of Beaumont during the later years for appropriators, and that these players saw more immediate consequences for stock at wells inside of Beaumont during our simulated period.

### 8.6 Equal Initial Property Rights Allocation Counterfactual

We next alter the design of property rights by allocating equal rights to each appropriator. Under the Beaumont Basin's judgment, appropriator rights were based on historical extraction. This impacts each of the appropriators in our model directly through their initial rights, and indirectly through their entitlment to unused overlyer rights in future years. While shares of these unused rights were allocated based on historical extraction, we instead re-allocate them equally.

As seen in Table 27, we find that differences were not statistically significant on the whole, but were significant and slightly positive in terms of consumer surplus generated. Consumer surplus increased by about half a quarter of a million dollars per year when allocations were equalized, although this was more than offset by a half million dollar decrease in appropriator producer surplus. This suggests that equal allocation may encourage some socially inefficient over-extraction by players with increased water reights. In Table 26 we find that appropriators did not benefit on the whole from the change.

As seen in Table 28, we find that appropriator extraction was actually re-balanced away from the Beaumont Basin for appropriators. The effect of the change appears to be contained to these players however. Stock was somewhat higher in the Beaumont Basin as a result. In Figures A.35- A.38, we show the evolution of counterfactual extraction and depth to groundwater by player type, alongside the actual values in our dataset. We seee that extraction was notably lower in Beaumont during the early years in our model before differences in stock levels lead to somewhat higher levels of extraction in the later years.

In Figures A.39-A.43, we see an interesting although expected pattern as players with higher actual initial allocations were given lower allocations in our counterfactual, and extracted much less water from Beaumont. On the other hand the two players with low actual initial allocations extracted much more water in the basin. This was somewhat balanced out by extraction outside of Beaumont. We see in the case of South Mesa Water Co., however, that overall extraction would have been significantly higher in our counterfactual, as extraction inside of Beaumont rose and was not offset by a decrease outside of Beaumont.

### 8.7 No Property Right to Recharged Water Counterfactual

We next alter the design of property rights by not allocating rights to recharged water for appropriators. Under the Beaumont Basin's judgment, appropriators were given rights any stored water that they recharged. This impacts two of the appropriators in our model directly through their property rights levels after recharge, and in future years.

In Table 30, we find that differences were not statistically significant on the whole, but were significant and slightly negative in terms of consumer surplus generated. Consumer surplus decreased by about half a tenth of a million dollars per year when allocations were not given to recharged water. Further, this was not offset by an increase in appropriator producer surplus. This suggests that appropriators may not have been able to extract as much without having these additional rights in the bank.

In Table 31 we find that appropriator extraction was re-balanced away from the Beaumont Basin for appprpopriators. The effect of the change appears to be contained to these players however. Stock was somewhat higher in the Beaumont Basin as a result. In Figures A.44- A.47, we show the evolution of counterfactual extraction and depth to groundwater by player type, alongside the actual values in our dataset. We see that extraction was notably lower in Beaumont during the later years in our model for apropriators, and that this was offset by higher extraction outside of Beaumont by these players. This suggests that the change in property rights took time to develop and influence extraction. In

In Figures A.48-A.52 we see that the player who recharged most water during this period, the Beaumont-Cherry Valley Water District, extracted less from the Beaumont Basin throughout the period, but especially in the later years when property rights to recharge would have acccumulated. This is not the pattern for other appropriators.

### 8.8 Revised Safe Yield Counterfactual

We next alter the design of property rights by using the updated estimate of safe yield produced after the property rights regime began operating. Under the Beaumont Basin's judgment, farmers were given the recurring right to the estimated safe yield of the basin. This safe yield was to be revised over time as part of the judgment. After 2014 the safe yield was revised downward. This resulted in a proportionate drop in recurring rights for overlyers, and a drop in any unused overlyer rights that were re-allocated to appropriators. This revision was based on a more up to date and accurate understanding of the basin's hydrology and thus represents a policy error in the initial allocation.

As seen in Table 33, we find that differences were not statistically significant on the whole, but were significant and slightly negative in terms of consumer surplus generated. Consumer surplus decreased by about half a tenth of a million dollars per year. Further, this was not offset by an increase in appropriator producer surplus. We also see that farmer profits inside of Beaumont were about a third lower after accounting for simulation bias. This suggests that farmers significantly reduced profitable extraction in response to lower property rights.

As seen in Table 34, we find that appropriator extraction was on average similar for appprpopriators. However farmers in the Beaumont basin would have had significantly lower extraction. In Figures A.53- A.56, we show the evolution of counterfactual extraction and depth to groundwater by player type, alongside the actual values in our dataset. We see that extraction was notably lower in Beaumont during the early years for farmers in the Beaumont basin, and that extraction remained lower in later years as well.

# 9 Discussion

## 9.1 Sources of Appropriator Welfare

In Table 9, we show that under the property rights regime appropriators derived significantly higher net benefits from groundwater extraction than their overlyer counterparts. Moreover the scale of these benefits are significantly higher than results that we previously found under open access (Sears et al., 2023c). This points to a combination of increased consumer surplus generated for customers through the use of outside water for sales to residential customers, and increased importance placed on factors not directly related to profits from imported water. In Figure 5, we plot water sales, population, and water sales per-capita over time for the appropriator group. Appropriators generated over $2 million in additional payoffs unrelated to water sales from their imported water, which was used either for sales to customers or recharging the basin. In addition, the imported water that was used for sales to customers generated consumer surplus. According to our model of residential water demand, this player was able to provide water more cheaply to their customers through their access to outside supplies, which generated higher profits.

Water sale profits did not add to the welfare of appropriators. In Table 9, we find that model simulated profits were actually negative during this period overall, meaning that appropriators revenues did not make up cost. They were also somewhat lower than what we found for groundwater profits in Sears et al. (2023c). This is likely due to the inclusion of the costs paid for imported water, which was not included in our calculation of producer profits from groundwater sales in our prior work.

We find that holding property rights for many periods did not directly contribute to higher appropriator welfare. However, the generation of property rights did create large payoffs when it was done through importing water. This is the most direct welfare contribution from the property rights system for appropriators. Here we also find that players were estimated to have negative values on holding their property rights. We conclude that holding property rights was generally given little weight.

## 9.2 Social Welfare

As discussed in our theory section, our player welfare estimates provide the valuation of water in dollar terms for each player group. Since for overlying players welfare is a discounted stream of profits, these terms can be counted directly as social welfare. However, while appropriators create social benefits through the consumer surplus they generate for their customers, as well as the profits they generate, and the cost savings generated by their property rights holdings, their payoff functions weigh these terms differently than society. As shown in our revenue function estimates, consumer surplus is generally weighted more highly at the margin than profits, while society values the two equally. To account for this, we construct a separate estimate of social welfare, in which we set the weight of consumer surplus to be equal to profits, and sum over the players in our game.

Table 10 shows our estimates of social welfare constructed using the actual observed data and the model simulated data. We find that total social welfare in our model simulated data reached just over \$32.7 million, with producer surplus actually estimated to be negative. Overall these results can be compared to results similar to those found in Sears et al. (2023c), to better understand the social benefits created by the property rights regime and how they were distributed.

### 9.3 Impact of Imported Water

In our theory model we found that recharge could be welfare improving, but that the most efficient policy equated marginal cost with the marginal social benefit provided by the recharged water. Our theory model also suggested that when a property rights regime awards extraction permits according to a one-to-one ratio with permit purchases (represented by recharge in our empirical model) that prices must rise in order for the price of permits to act as an effective price signal. Here the price of recharge was not chosen by the regulator, and as a result could not guarantee that either of these conditions were met. Prices for imported water were on average \$425 per acre-foot. We find that the average social value of water during the period was only around \$62 per acre-foot, while the private average payoffs per acre-foot for appropriators was around \$70 [10]. This suggests that the price signal was indeed not effective, and that players may have chosen to purchase imports in order to accumulate pumping rights for future years when the price of imports and recharge might be expected to be much higher and they may face a binding constraint from their permit stock. This is reflected in the payoffs for imported water which are significantly higher than payoffs from groundwater extraction in the present. In our counterfactual analysis we find that when we remove the option to recharge water, players adjust by reducing their extraction at wells inside the Beaumont Basin, and re-allocate to wells outside the Beaumont Basin. Thus in a scenario where water rights can not be augmented through recharge, the short term response by players is to save water rights by extracting less in the present. This is likely a socially and privately inefficient balancing of extraction, since it suggests that the marginal payoff from extraction will at some point in the future be significantly higher than in the present, suggesting that extraction is expected to have to be curtailed significantly in the future. Players could instead lower extraction in the present to better balance out extraction over the long term and raise their total payoffs. Their current behavior likely reflects constraints on their extraction at wells outside of Beaumont and their ability to raise prices and reduce consumption in the present.

An alternative hypothesis for the impact of changes in water imports on extraction could be that recharge augments the groundwater stock in the future, leading to higher extraction in future years, and thus lower marginal value extraction. In response players extract more in the present driving down their current period marginal profits. When imports are taken away, they react by decreasing extraction in the present, and re-allocate some extraction to other sources of water that are not directly

[10] To compute the average social value we take the actual total social welfare and divide by the sum of total extraction and water imports by all players. For average private value for appropriators we take total actual welfare for appropriators and divide by the sum of total extraction and water imports by appropriators.

affected by the loss of imports. However, our counterfactual analysis of a scenario in which water rights for recharged water are withdrawn suggests that players are actually responding to changes in their water rights stock more than changes in the physical stock of groundwater. In this scenario players still recharge water, although slightly less than in the baseline. Thus the groundwater stock effect from recharge is still present. However, they do not receive any additional water rights, and still re-allocate their extraction away from the Beaumont Basin, to wells outside of the adjudicated zone. Thus it appears that in the short term, players react more to changes in the property rights stock than to changes in the physical stock of groundwater.

## 9.4 Property Rights Design

A key advantage of tradable permit schemes is the idea that under transaction costless trading, initial allocation does not matter for efficiency, and water rights can be grandfathered to players to induce their cooperation (Montgomery, 1972; Stavins, 1995, 1998). However, as is clear from the limited amount of water rights trading, there appear to be significant transaction costs, and thus we would expect for initial allocation to impact efficiency. Our counterfactual analysis of a scenario in which trading is curtailed showed little impact on social welfare, an unsurprising result given the volume of trading observed. When we alter the initial allocation of water rights, so that they are allocated equally among players, we find that there is a substantial impact on behavior of players. Appropriators extract more on average and social welfare decreased slightly compared to the baseline. This suggests that the allocation based on historical extraction was a slight improvement over an equal allocation regime in the context of limited trading. Thus, there was indeed heterogeneity in the profitability of extraction in the Beaumont Basin region among these players. Avoiding grandfathering then, and auctioning water rights, would be expected to induce additional social benefits. Importantly avoiding using historical extraction as a basis for determining the allocation of water rights also would prevent players from raising their extraction under open access in the hope of gaining additional water rights in the future under an adjudication. If grandfathering is indeed necessary for a property rights regime to be accepted, then watermasters must work to limit transaction costs to trading. This can happend through expanding the scope of the market to include a larger number of participants, and acting as a broker between players.

## 9.5 Market Mechanisms and Groundwater Property Rights

A key finding of Sears et al. (2023c) was that the Beaumont Basin adjudication influenced the extraction behavior of players but had only a modest impact on social welfare. A key question from that analysis was whether the market for water pumping rights was what influenced extraction, or whether the advent of imported water in the region was the true cause. This paper provides substantial evidence that the property rights regime did influence the actions of players in the region, even after accounting for the impact of imports on the stock of groundwater. However, the evidence from our paper points to the limitations that market based mechanisms face in confronting groundwater management in California, in particular legal, spatial, and technological constraints.

Market mechanisms rely upon the transferability of permits for a resource to promote trading and allocate extraction of the resource to the use that is most beneficial (Blomquist, 2020). However, our case study shows that trading was not prevalent between users, and that marginal payoffs from extraction varied widely across users. This points to the legal constraints placed on transferability across players with different types of water rights. While such transfers were allowed in Beaumont, they required appropriators to extend service connections to overlying users. Beyond the legal constraints, the relatively small geographic scope of the adjudication and the water rights system also likely limited the amount of water rights trading between appropriators. Groundwater regulation under SGMA is done at the local level, and will also likely face this obstacle.

The significant amount of artificial recharge and water importing done by players in the dynamic game suggests that the water rights system did create a market signal for the value of groundwater. We see for example that when water rights allocation was taken away for recharge, that players adjusted their extraction in the Beaumont Basin in order to conserve water rights for future years, suggesting that the water rights were indeed scarce. This indicates that players did expect to be able to capture their water rights in future years, and thus that they were dynamically optimizing. However, the large gap between the price players were willing to pay for imports, and the relatively low value of current groundwater extraction point to the expectations players have about the rising cost of imports in the future, and the political and legal constraints they may face in the present. While it may indeed be efficient to continue paying for any available water imports in the present, it would also be more efficient to raise prices and signal to consumers the high long term cost of water, which would help to better balance out consumption over the long term. Raising prices should be done with an eye to equity so that rising prices do not place an undue burden on low income households (Cardoso and Wichman, 2021).

### 9.6 Conclusion

To measure the impact of policy design on social welfare we make use of a structural econometric model of a dynamic groundwater extraction and managed artificial recharge game played between groundwater users in the years following the adjudication of the Beaumont Basin in Southern California. Our choice to use a structural model allows us to estimate parameters in the payoff functions of players that allow us to quantify the effect of the policy on both consumer and producer surplus in the region. In addition our approach allows us to capture the spatial, dynamic, and strategic aspects that help determine the behavior of players and how this behavior transmits to changes in the stock of groundwater and the long-term social welfare in the region. To estimate our model we incorporate a realistic underlying model of the property rights system that was imposed following the adjudication as well as a model of residential water demand. We harness variation in the level of stock and weather conditions across space and over time, the state of the regional economy over time, the allocation and design of property rights dynamics across players, and the observed extraction and recharge decisions of each of the players.

Thus our paper provides empirical and theoretical insights about the ways in which the dual rights system in California shapes the economic efficiency of groundwater use. We find that while tradable and storable property rights can theoretically induce more efficient groundwater extraction behavior by creating a market for rights to extract, California's legal institutions place important limitations on the efficiency with which these markets operate. Distinguising between overlying and appropriator property rights prevents the most efficient initial allocation of water rights through mechanisms like auctioning. Moreover, alongside the small scale of these markets, they prevent the wide scale trading of water rights between users in practice, making the inefficiency of the initial allocation even more problematic. Finally, by linking the price of permits to the price of water imports, they do not allow the watermaster the ability to price permits in an intertemporally efficient manner.

Policymakers should examine options that are consistent with SGMA and property rights law to improve the efficiency of these markets. Linking water rights systems to include other nearby hydrologically linked groundwater basins, would create larger more liquid rights markets could be an option to increase the prevalence of trading. However, due to the spatial heterogeneity in how extraction is transmitted to changes in shared groundwater stocks, it may be necessary to use mechanisms like trading ratios in order to prevent access to groundwater from being cutoff from efficient uses (Blomquist, 2020). Similarly, reflecting the explicity guideline that SGMA does not allow groundwater sustainability agencies to alter existing property rights to groundwater, these agencies should examine methods to temporarily adjust pumping rights to implement intertemporal trading ratios that can bring in line the price path of recharge with the scarcity value of groundwater stock. If the price of recharge is expected to rise faster than the private interest rate used by players to discount the future, and the scarcity value of groundwater stock is rising more slowly, then a one-to-one savings rate on permits is inefficient. Temporarily limiting the return on water rights, or placing a lag on when these water rights are accessible would help to reduce extraction without reducing recharge based on our counterfactual analysis.

Thus our work highlights the need for continued research on groundwater markets. SGMA's implementation will provide significantly more data on how these markets function, as well as variation in the design of these systems. As groundwater stocks face the strain of more extreme weather under projected changes to the climate in California, making use of these policy experiments will be vital for designing policies that are legally robust and economically efficient in the future.

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Table 1: Policy Function Results, 2004-2013

| | *Dependent variable is:* | |
|---|---|---|
| | Appropriator total extraction (acre-feet) | Appropriator share extraction in Beaumont |
| | (1) | (2) |
| ETo, inches, lag | | -0.0498* |
| | | (0.0200) |
| Retail price, untreated water, dollars/acre-foot | | 0.000437*** |
| | | (5.37e-05) |
| Precipitation (Jan-Mar) | | -0.00235** |
| | | (0.000899) |
| Distance to Beaumont Recharge facility, feet | | 6.95e-05*** |
| | | (6.87e-06) |
| Average distance to other player wells in same basin | | 0.760*** |
| | | (0.0865) |
| Extraction at wells inside Beaumont Basin, lag | | 5.01e-05*** |
| | | (4.19e-06) |
| Depth to groundwater outside management zone, feet | -16.36** | 0.00270*** |
| | (5.965) | (0.000537) |
| Water surface elevation, feet above sea level, all wells not owned by i in manag | | -0.00156*** |
| | | (0.000141) |
| Gains access to artificial recharge next period X Saturated hydraulic conductivity at wells out | | 0.00221*** |
| | | (0.000338) |
| Gains access to artificial recharge X Saturated hydraulic conductivity at wells outside Beaumon | | 0.00181*** |
| | | (0.000331) |
| Property rights allocation, net of recharge, plus remaining surplus allocation | 0.0458*** | 7.63e-06*** |
| | (0.00974) | (7.84e-07) |
| Electricity price, first-difference | | 1.258*** |
| | | (0.273) |
| Depth to groundwater inside management zone, feet | 19.65* | |
| | (7.745) | |
| Population of city in service area | 0.197*** | |
| | (0.0236) | |
| SWP filtered water sales, lag | -0.679*** | |
| | (0.0747) | |
| Extraction inside Beaumont Basin X Riverside County housing starts, first differ | -2.82e-05*** | |
| | (3.98e-06) | |
| Saturated hydraulic conductivity at wells inside Beaumont Basin X Evapotranspiration (in) | -19.20*** | |
| | (5.640) | |
| Average distance to other players wells in Beaumont Basin X Water surface elevat | 0.552*** | |
| | (0.101) | |
| Precipitation, (Apr-Oct) lag X Extraction at wells inside Beaumont Basin, lag | -0.0247** | |
| | (0.00939) | |
| OLS | N | Y |
| System GMM | Y | N |
| # Observations | 40 | 40 |
| # Players | 4 | 4 |
| p-value (Prob>F) | 0.000 | 0.000 |
| RMSE | 549.4 | 0.0243 |

Notes: Standard errors in parentheses. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table 2: Policy Function Results, 2004-2013

| | *Dependent variable is:* | | |
|---|---|---|---|
| | Farmer extraction outside Beaumont (acre-feet) | Farmer extraction inside Beaumont (acre-feet) | Recreational extraction (acre-feet) |
| | (1) | (2) | (3) |
| Average distance to other player wells in same basin | | | -79.33 |
| | | | (45.96) |
| Electricity price, first-difference | | -4,846*** | |
| | | (684.8) | |
| Depth to groundwater, feet | -2.044*** | -12.77*** | 2.238** |
| | (0.159) | (0.508) | (0.854) |
| Depth to groundwater, squared | 0.00571*** | | |
| | (0.000539) | | |
| Electricity price, agricultural, dollars/kwh | -566.3*** | | |
| | (112.4) | | |
| March price, oranges, dollars/box | 2.196* | -18.11*** | |
| | (0.987) | (5.006) | |
| Distance to artificial recharge facility at wells outside Beaumont Basin | -0.0346*** | | |
| | (0.00185) | | |
| Saturated hydraulic conductivity, ft/day | 1.098*** | | |
| | (0.195) | | |
| Elevation, mean feet above sea-level | 0.192*** | | |
| | (0.00550) | | |
| Inches precipitation, (Apr-Oct) | -2.022* | 14.75* | |
| | (1.012) | (6.294) | |
| Recharge, lag | | -0.0427*** | |
| | | (0.00423) | |
| Property rights allocation, net of trades | | 2.384*** | |
| | | (0.0913) | |
| Non-retirement home dummy X Saturated hydraulic conductivity X Electricity price | | | -56.44*** |
| | | | (15.03) |
| Golf course dummy X California Real GDP per capita | | | 0.0190*** |
| | | | (0.00143) |
| Golf course dummy X Unemployment rate (percent) | | | -50.00*** |
| | | | (6.732) |
| Property rights allocation, initial balance | | | 0.313*** |
| | | | (0.0543) |
| Constant | | 1,699*** | |
| | | (69.06) | |
| OLS | N | N | N |
| System GMM | Y | Y | Y |
| # Observations | 40 | 19 | 44 |
| # Players | 4 | 2 | 5 |
| p-value (Prob>F) | 0.000 | 0.000 | 0.000 |
| RMSE | 17.79 | 33.31 | 99.70 |

Notes: Standard errors in parentheses. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table 3: Policy Function Results, 2004-2013

| | *Dependent variable is:* | | |
|---|---|---|---|
| | Appropriator artificial recharge (acre-feet) | Appropriator imported water sales (acre-feet) | Well drilling (dummy) |
| | (1) | (2) | (3) |
| Population of city in service area | 0.227*** | | |
| | (0.0132) | | |
| Extraction inside Beaumont Basin X Riverside County housing starts, first difference | 1.48e-05 | | |
| | (7.27e-06) | | |
| Recharge, first difference, lag | 0.763*** | | |
| | (0.124) | | |
| Saturated hydraulic conductivity X California Real GDP per capita | -0.00154*** | | |
| | (0.000170) | | |
| Traded property rights | -0.696* | | |
| | (0.264) | | |
| ln(RGDPPC-CA)-L4.ln(RGDPPC-CA) | -6,884* | | |
| | (2,709) | | |
| Degree-days (¿90 F), (Apr-Oct) | | 86.58*** | |
| | | (19.97) | |
| Stream flow, cubic feet per second | | -3.378* | |
| | | (1.585) | |
| Riverside County housing starts | | -0.157*** | |
| | | (0.0337) | |
| Property right allocation, plus remaining surplus allocation | | 0.0857 | |
| | | (0.109) | |
| Depth to groundwater, squared, feet | | | -4.02e-05*** |
| | | | (9.58e-06) |
| Appropriator (dummy) | | | -0.920** |
| OLS | N | Y | N |
| System GMM | Y | N | N |
| Probit | N | N | Y |
| # Observations | 14 | 10 | 188 |
| # Players | 2 | 1 | 19 |
| p-value (Prob>F) | 0.000 | 0.000 | 0.000 |
| RMSE | 538.6 | 509.9 | - |

Notes: Standard errors in parentheses. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table 4: State Transition Results, 1991-1996

| | *Dependent variable is depth to groundwater (feet) for:* | | | | |
|---|---|---|---|---|---|
| | Farmer outside Beaumont | Farmer inside Beaumont | Recreational | Appropriator inside Beaumont | Appropriator outside Beaumont |
| | (1) | (2) | (3) | (4) | (5) |
| *Lagged values of:* | | | | | |
| Depth to groundwater, feet | 0.562*** | 0.993*** | 0.824*** | | |
| | (0.144) | (0.00572) | (0.0569) | | |
| Precipitation Jan-March, inches | 1.453*** | 0.437* | 1.768*** | | |
| | (0.261) | (0.213) | (0.318) | | |
| Inches precipitation, full year | -0.693*** | | -0.933*** | | |
| | (0.178) | | (0.197) | | |
| Extraction at wells owned by others, 3 to 4 miles | 0.00225** | | 0.00123* | | |
| | (0.000796) | | (0.000515) | | |
| Extraction at wells owned by others, 1 to 2 miles | -0.00106 | | | | |
| | (0.00364) | | | | |
| Log CA real GDP per capita, 1997 dollars | 7.119** | | | -23.15*** | |
| | (2.467) | | | (4.587) | |
| Hydrocond., ft/day | 14.94*** | | | | |
| | 2 (2.626) | | | | |
| Hydrocond. X water elevation, others outside Beaumont | -0.00478*** | | | | |
| | (0.000841) | | | | |
| Retail price, untreated water, dollars/acre-foot | -0.0188 | | | | |
| | (0.0173) | | | | |
| Total extraction, acre-feet | | 0.00647*** | -0.00912** | | |
| | | (0.00183) | (0.00299) | | |
| Inches precipitation, (Apr-Oct) | | -0.973* | | -0.952* | |
| | | (0.477) | | (0.408) | |
| Water elevation (ft above sea level) | | | 0.0802*** | | |
| | | | (0.0239) | | |
| Surface water elevation measurement | | | -4.828* | | |
| | | | (2.120) | | |
| Average distance to other player wells in same basin | | | -28.35** | | |
| | | | (10.07) | | |
| Available Table A allocation, SWP | | | -0.000804*** | | |
| | | | (0.000231) | | |
| Depth to groundwater inside Beaumont, feet | | | | 0.426*** | |
| | | | | (0.0928) | |
| Hydrocond. in Beaumont, ft/day | | | | 0.488** | |
| | | | | (0.175) | |
| Ext. at wells inside Beaumont by others, 0.5 to 1 miles | | | | -0.0441** | |
| | | | | (0.0162) | |
| Ext. at wells inside Beaumont by others, 1 to 2 miles | | | | 0.0135*** | |
| | | | | (0.00348) | |
| Log population of service area | | | | 35.42*** | |
| | | | | (6.303) | |
| Total artificial recharge/Distance to recharge facility | | | | -17.81*** | |
| | | | | (2.855) | |
| Depth to groundwater outside Beaumont, feet | | | | | 0.808*** |
| | | | | | (0.0447) |
| Distance to recharge facility at wells outside Beaumont | | | | | -0.00533*** |
| | | | | | (0.00128) |
| March price, strawberries, dollars/lb | | | | | -20.42*** |
| | | | | | (2.530) |
| CA real GDP per capita, 1997 chained dollars | | | | | 0.00155*** |
| | | | | | (0.000293) |
| OLS | Y | N | N | N | Y |
| GMM | N | Y | Y | Y | N |
| # Observations | 40 | 20 | 44 | 40 | 40 |
| # Players | 4 | 2 | 5 | 4 | 4 |
| p-value (Prob > F) | 0 | 0 | 0 | 0 | 0 |
| RMSE | 7.964 | 4.054 | 4.767 | 5.531 | 3.355 |

Notes: Standard errors in parentheses. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table 5: Revenue Parameters

| | Revenue Parameters |
|---|---|
| *Coefficient in Farmer Marginal Revenue on:* | |
| Precipitation (inches) | 25.002* |
| | (9.75) |
| Average crop price (dollars per unit) | -0.027 |
| | (0.207) |
| Has wells inside Beaumont Basin dummy | 79.13*** |
| | (22.966) |
| *Coefficient in Recreational User Marginal Revenue on:* | |
| Golf course (dummy) | -11,818.146*** |
| | (1859.605) |
| Golf course (dummy) X Real GDP per capita ($1,000) | 210.778*** |
| | (34.073) |
| Retirement home (dummy) | -0.968 |
| | (5.038) |
| Constant | 52.687*** |
| | (6.541) |
| *Coefficient in Appropriator Marginal Revenue on:* | |
| Full year evapotranspiration (inches) | -22.384** |
| | (7.095) |
| *Weight in Appropriator Per-Period Payoffs on:* | |
| Consumer surplus | 0.466*** |
| | (0.065) |
| Consumer surplus, squared | 0.000000036*** |
| | (0.000) |
| Profits from water sales | 1.000 |
| | (normalization) |

Notes: Per-period payoffs, revenue, and marginal revenue are in dollars. Standard errors are in parentheses. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table 6: Cost of Water Extraction and Well Drilling

| | Appropriators | Farmers | Recreational |
|---|---|---|---|
| *Coefficient in Water Extraction Cost on:* | | | |
| Extraction per well (acre-feet) squared | -0.00563* | 0.24** | 0.004 |
| | (0.003) | (0.077) | (0.006) |
| *Coefficient in Well Drilling Cost on:* | | | |
| Number of new wells × Depth to groundwater (100 ft) | 45,984.8*** | | |
| | (10,593.6) | | |

Notes: Costs are in dollars. Standard errors are in parentheses. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table 7: Marginal Value of Property Rights and Imported Water

| | *Coefficient in Property Right and Imported Water Value on:* | | | | |
|---|---|---|---|---|---|
| | Property Rights Net of Recharge Extraction Ratio | Overlyer Property Rights Extraction Ratio | Artificial Recharge Constant | Filtered Sales Constant | Artificial Recharge X Distance to Recharge Facility |
| Coefficient | -78,335.55 | -1642.73 | 351.67*** | 390.78*** | 0.014* |
| | (178,649.54) | (1488.01) | (27.92) | (25.02) | (0.007) |

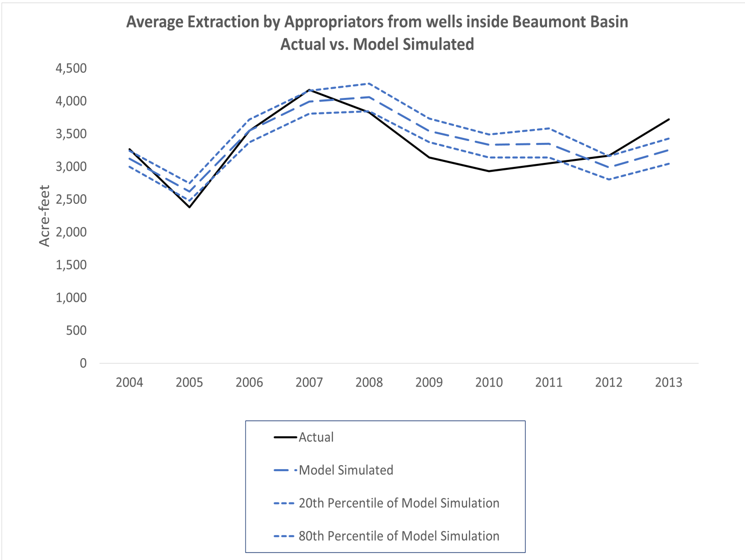
| | Total Average Effects |
|---|---|
| Property Rights, Appropriators | 0.37 |
| Property Rights, Overlyers | 1.98 |
| Artificial Recharge | 416.97*** |
| SWP Filtered Sales | 390.78*** |

Notes: Values are in dollars. Standard errors are in parentheses. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

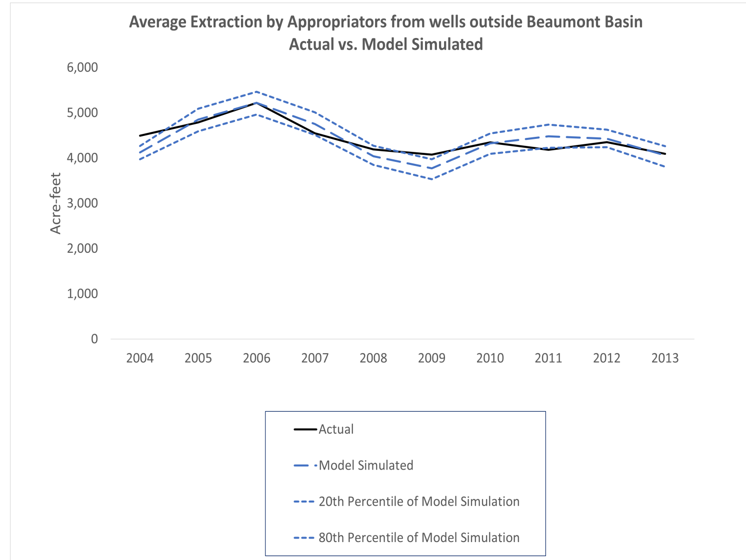
Table 8: Model Fit Simulation Statistics, 2004-2013

| | Appropriator inside Beaumont | Appropriator outside Beaumont | Farmer inside Beaumont | Farmer outside Beaumont | Recreational User | Appropriator Imported Water |
|---|---|---|---|---|---|---|
| | | *Groundwater Extraction (acre-feet)* | | | | *Artificial Recharge (acre-feet)* |
| Model Simulated Data | | | | | | |
| Mean | 3381.30 | 4403.46 | 275.91 | 218.90 | 518.96 | 3620.98 |
| Std Dev | 3504.96 | 2725.90 | 378.41 | 218.90 | 431.93 | 2368.13 |
| Actual Data After Institution of Property Rights | | | | | | |
| Mean | 3319.90 | 4426.40 | 257.42 | 218.38 | 590.17 | 3631.94 |
| Std Dev | 3621.51 | 2776.24 | 391.34 | 152.58 | 418.02 | 2508.99 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | 0.018 | -0.005 | 0.128 | 0.002 | -0.001 | -0.003 |
| Std Dev | 0.203 | 0.149 | 0.292 | 0.121 | 0.241 | 0.308 |
| | | *Depth to Groundwater (feet)* | | | | *Filtered Sales (acre-feet)* |
| Model Simulated Data | | | | | | |
| Mean | 187.79 | 132.61 | 283.79 | 207.98 | 242.21 | 4763.32 |
| Std Dev | 48.71 | 37.16 | 85.11 | 207.98 | 87.45 | 2424.05 |
| Actual Data After Institution of Property Rights | | | | | | |
| Mean | 187.54 | 132.05 | 285.98 | 207.59 | 242.57 | 4754.30 |
| Std Dev | 48.36 | 36.70 | 86.69 | 47.85 | 83.64 | 2222.38 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | 0.001 | 0.004 | -0.008 | 0.002 | -0.003 | 0.002 |
| Std Dev | 0.048 | 0.045 | 0.015 | 0.062 | 0.033 | 0.154 |

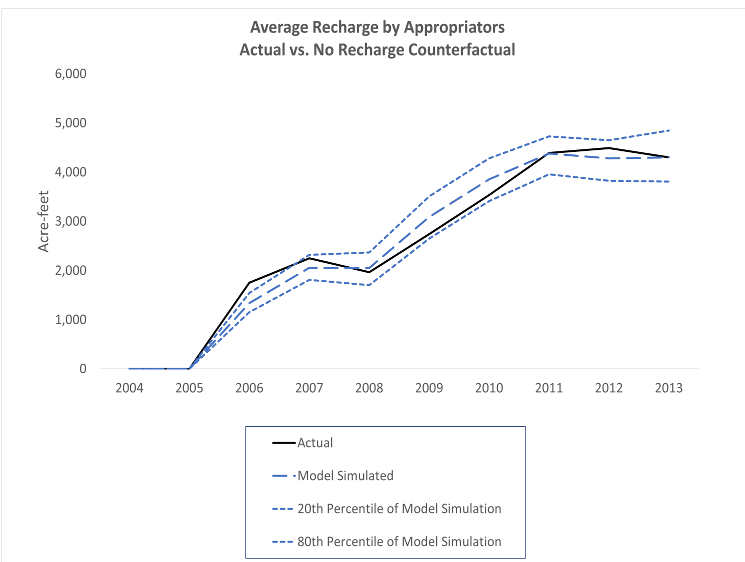
Notes: This table compares the model predicted actions and states with the actual actions and states in the data.



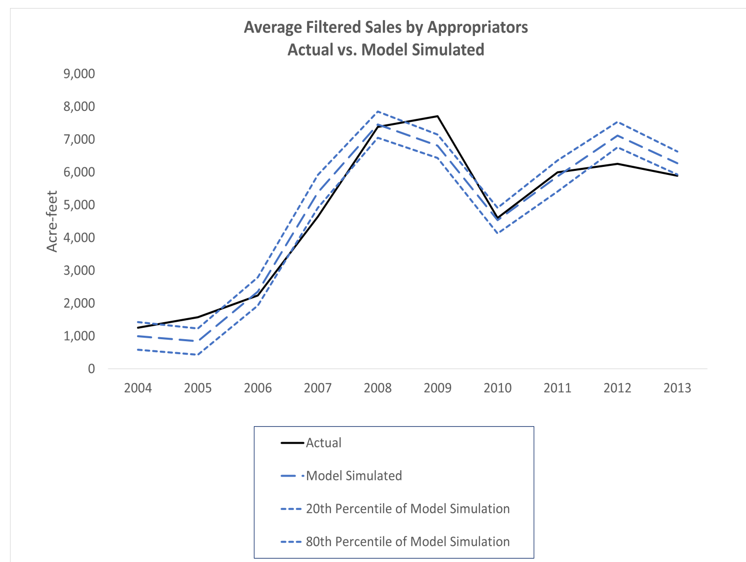

(a) Appropriator Extraction
inside Beaumont Basin




(b) Appropriator Extraction
outside Beaumont Basin

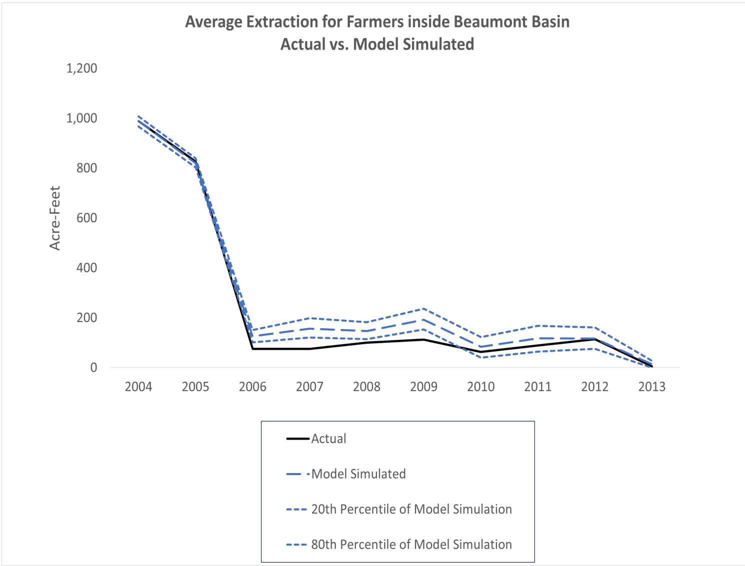



(c) Appropriator
Recharge

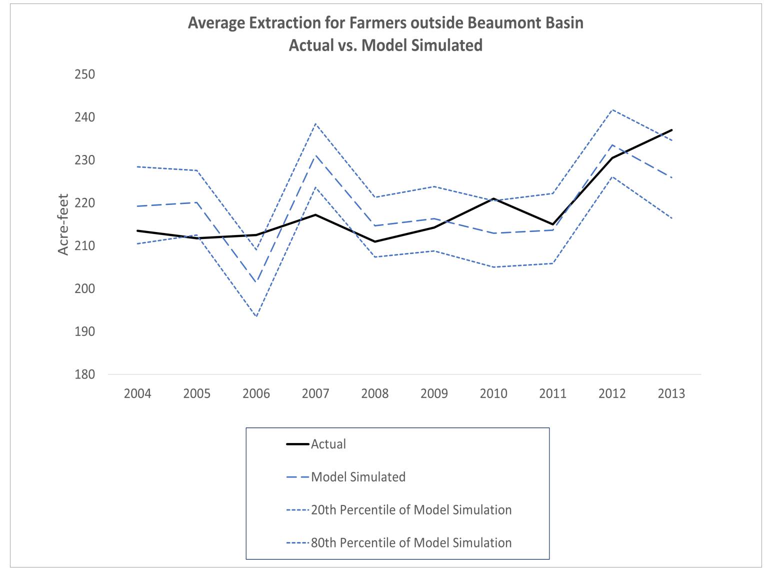



(d) Appropriator
Filtered Sales

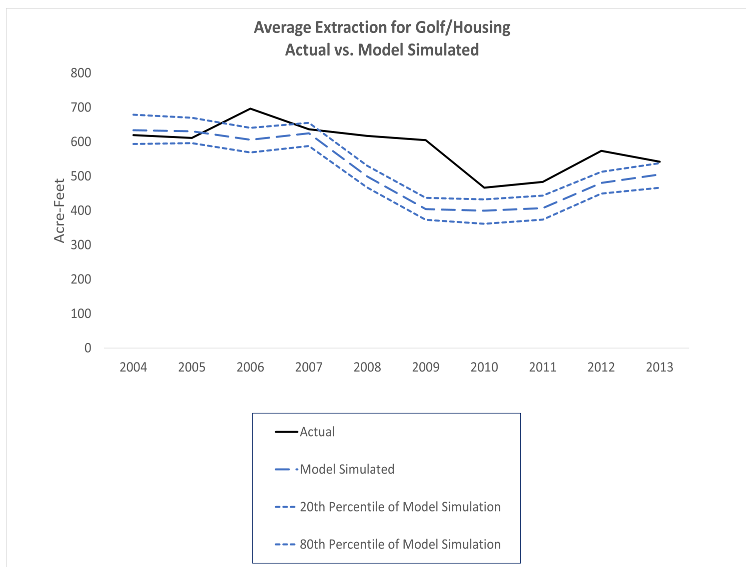
Figure 1: Model Fit: Appropriator Behavior




(a) Farmer Extraction inside Beaumont Basin

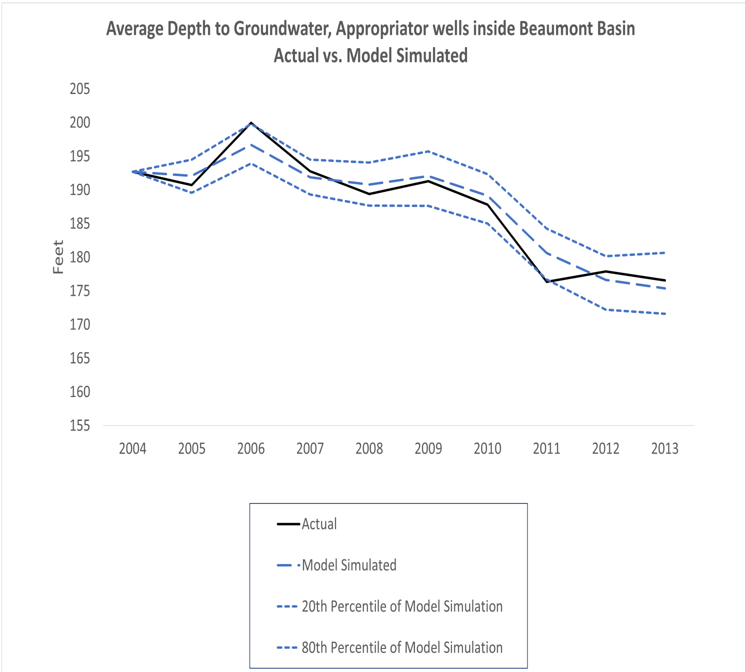



(b) Farmer Extraction outside Beaumont Basin

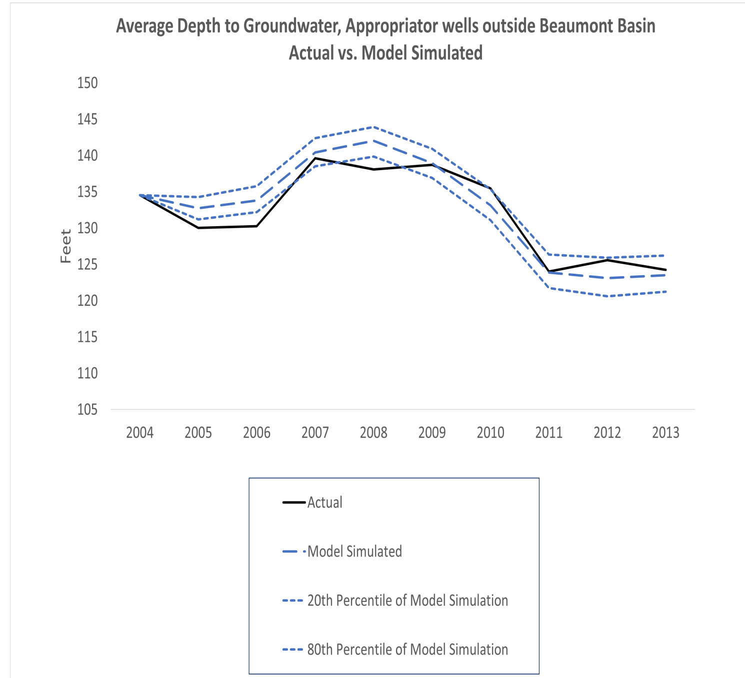



(c) Recreational User Extraction

Figure 2: Model Fit: Overlyer Behavior

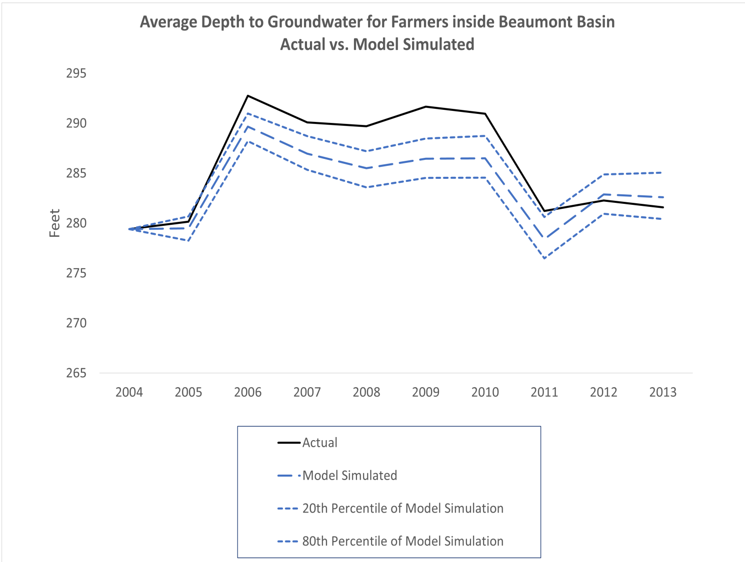



(a) Appropriator Depth to Groundwater inside Beaumont Basin

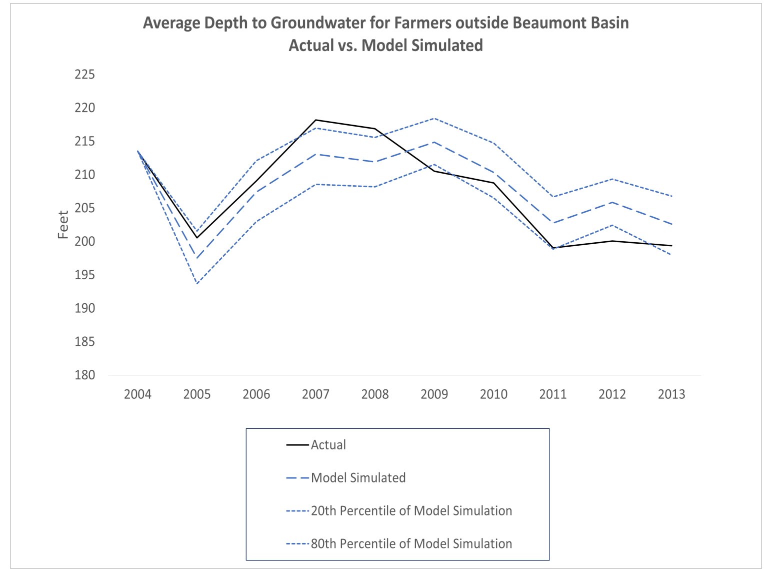



(b) Appropriator Depth to Groundwater outside Beaumont Basin

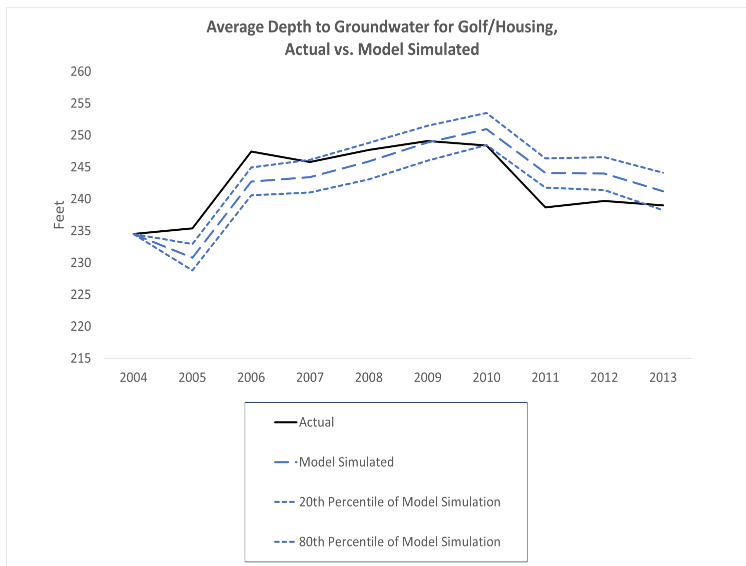
Figure 3: Model Fit: Appropriator Depth to Groundwater




(a) Farmer Depth
to Groundwater
inside Beaumont Basin




(b) Farmer Depth
to Groundwater
outside Beaumont Basin




(c) Recreational User
Depth to Groundwater

Figure 4: Model Fit: Overlyer Depth to Groundwater

Table 9: Model Predicted Average Annual Welfare, Consumer Surplus, and Profits, 2004-2013

| Player | Model Predicted | | | | |
|---|---|---|---|---|---|
| | *Welfare (dollars)* | *Consumer Surplus (dollars)* | *Profits (dollars)* | *Revenues (dollars)* | *Costs (dollars)* |
| Appropriators | | | | | |
| Beaumont-Cherry Valley Water District | 8 million | 8.7 million | -1.4 million | -0.2 million | 1.2 million |
| City of Banning | 7.1 million | 7.9 million | -0.3 million | 0.1 million | 0.4 million |
| South Mesa Water Company | 1.8 million | 2.8 million | 0.1 million | 0.1 million | 0.03 million |
| Yucaipa Valley Water District | 14.4 million | -3.7 thousand | -2.7 million | -1.3 million | 1.3 million |
| **Total Appropriator** | **31.4 million** | **32.7 million** | **-4.3 million** | **-1.3 million** | **3 million** |
| Farmers in Beaumont Basin | | | | | |
| Sunny-Cal Egg | 18.9 thousand | | 19.2 thousand | 62.4 thousand | 43.2 thousand |
| Riedman | 6.7 thousand | | 7.2 thousand | 27.7 thousand | 20.6 thousand |
| **Total Farmers in Beaumont Basin** | **25.6 thousand** | | **26.3 thousand** | **90.1 thousand** | **63.8 thousand** |
| Farmers outside Beaumont Basin | | | | | |
| Dowling | 0.8 thousand | | 0.8 thousand | 4.2 thousand | 3.4 thousand |
| Illy | 4.6 thousand | | 4.6 thousand | 16.7 thousand | 12.1 thousand |
| Summit | 0 thousand | | 0 thousand | 4.1 thousand | 4.1 thousand |
| Hudson | 8.4 thousand | | 8.4 thousand | 36 thousand | 27.5 thousand |
| **Total Farmers outside Beaumont Basin** | **13.7 thousand** | | **13.7 thousand** | **60.9 thousand** | **47.2 thousand** |
| Recreational Users | | | | | |
| California Oak Valley Golf and Resort LLC | -19.1 thousand | | -18.2 thousand | 25.7 thousand | 43.9 thousand |
| Southern California PGA | 20.5 thousand | | 21.1 thousand | 52.2 thousand | 31.1 thousand |
| Oak Valley Partners | 0.1 thousand | | 0.4 thousand | 16.2 thousand | 15.8 thousand |
| Plantation on the Lake | -0.4 thousand | | 0.2 thousand | 11.4 thousand | 11.2 thousand |
| Sharondale Mesa Owners Association | -0.4 thousand | | 0.6 thousand | 6.2 thousand | 5.6 thousand |
| **Total Recreational Users** | **0.8 thousand** | | **4.1 thousand** | **111.6 thousand** | **107.6 thousand** |

Notes: Average annual welfare, profits, revenues, and costs are the present discounted value of the entire stream over the period 2004-2013 of per-period payoffs, profits, revenues, and costs, respectively, divided by the number of years. Consumer surplus is the consumer surplus faced by each appropriator over the period 2004-2013. Average annual consumer surplus is consumer surplus divided by the number of years. For farmers and recreational users, average annual welfare is equal to average annual profits. For appropriators, profits are the profits from water sales given by the water sale revenues minus extraction costs, while the per-payoffs are a weighted quadratic function of consumer surplus and the profits from water sales. Model predicted welfare and profit components are calculated using the parameter estimates from the structural model, and the model predicted actions and states. Model predicted consumer surplus is calculated using the water demand parameter estimates, and the model predicted actions and states.

Table 10: Model Predicted Average Annual Social Welfare from Groundwater, 2004-2013

| | Model Predicted |
|---|---|
| *Average Annual Profits (dollars)* | |
| Appropriator profits | -4.3 million |
| Farmer profits inside Beaumont Basin | 25.6 thousand |
| Farmer profits outside Beaumont Basin | 13.7 thousand |
| Recreational user profits | 0.8 thousand |
| **Total Profits** | **-4.26 million** |
| *Average Annual Consumer Surplus (dollars)* | |
| Beaumont-Cherry Valley Water District | 8.7 million |
| City of Banning | 7.9 million |
| South Mesa Water Company | 2.8 million |
| Yucaipa Valley Water District | 13.3 million |
| **Total Consumer Surplus** | **32.7 million** |
| *Average Annual Value of Property Rights (dollars)* | |
| Beaumont-Cherry Valley Water District | -9.8 thousand |
| City of Banning | -2.7 thousand |
| South Mesa Water Company | -3.2 thousand |
| Yucaipa Valley Water District | -3.7 thousand |
| Farmers inside Beaumont Basin | -0.8 thousand |
| Recreational Users | -3.3 thousand |
| **Total Value of Property Rights** | **0 million** |
| *Average Annual Value of Imported Water (dollars)* | |
| Beaumont-Cherry Valley Water District | 858.9 thousand |
| City of Banning | 210.8 thousand |
| South Mesa Water Company | N/A |
| Yucaipa Valley Water District | 1063.2 thousand |
| **Total Value of Imported Water** | **2.1 million** |
| **Social Welfare** | **30.6 million** |

Notes: Components of social welfare are the present discounted value of the entire stream of per-period payoffs related to each component over the period 1991-1996. Producer surplus is equal to the profits from groundwater extraction summed over all players, plus the value of holding property rights for appropriators. Consumer surplus is the consumer surplus faced by each appropriator, and is not weighted by parameters in the payoff function of the appropriator. Social welfare is equal to the sum of producer surplus and consumer surplus. Average annual values of these components are equal to the total value of the component divided by the number of years. Model predicted profits are calculated using the parameter estimates from the structural model. Model predicted consumer surplus are calculated using the water demand parameter estimates. Model predicted values are calculated using model predicted actions and states generated from 100 simulation runs of the open access period.

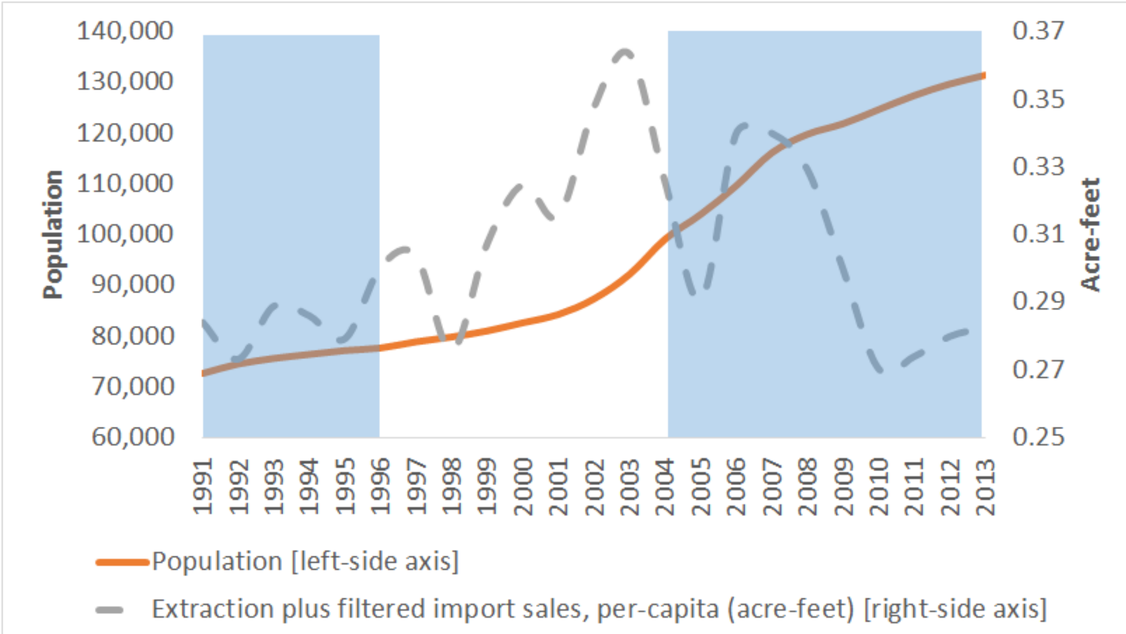



Figure 5: Trends in Population and Water Consumption, 1991-2013

Table 11: No Artificial Recharge Counterfactual: Average Annual Welfare, 2004-2013

| Player | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Appropriator Profits | | | |
| Beaumont-Cherry Valley Water District | -1.3 million | 0.8 million *** | 1 million *** |
| City of Banning | -0.2 million | 0.1 million | 0.2 million * |
| South Mesa Water Company | 0 million | 0 million | -0.1 million |
| Yucaipa Valley Water District | -2.5 million | -0.3 million | -0.1 million |
| **Total appropriators** | **-3.9 million** | **0.7 million** | **1.1 million** |
| | | *Average Annual Welfare (dollars)* | |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | 8.1 million | 0.9 million | 0.1 million |
| City of Banning | 7.1 million | 0.7 million | 0 million |
| South Mesa Water Company | 1.8 million | 0.2 million | 0 million |
| Yucaipa Valley Water District | 14.4 million | 1.4 million | 0 million |
| **Total appropriators** | **31.5 million** | **3.2 million** | **0.1 million** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 20.2 thousand | 3.3 thousand | 1.3 thousand |
| Riedman | 4.1 thousand | -1.8 thousand | -2.6 thousand |
| **Total farmers in Beaumont Basin** | **24.3 thousand** | **1.5 thousand** | **-1.3 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | 0.8 thousand | -0.2 thousand | 0 thousand |
| Illy | 4.6 thousand | 0.3 thousand | 0 thousand |
| Summit Cemetery District | -0.5 thousand | -1.9 thousand | -0.5 thousand |
| Hudson | 8.3 thousand | 0.7 thousand | -0.1 thousand |
| **Total farmers outside Beaumont Basin** | **13.2 thousand** | **-1.2 thousand** | **-0.6 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | -20.2 thousand | 2.4 thousand | -1.1 thousand |
| Southern California PGA | 20.8 thousand | -6.8 thousand | 0.3 thousand |
| Oak Valley Partners | 0.1 thousand | 0.2 thousand | 0 thousand |
| Plantation on the Lake | -0.3 thousand | -0.3 thousand | 0.1 thousand |
| Sharondale Mesa Owners Association | -0.4 thousand | -0.1 thousand | 0 thousand |
| **Total recreational users** | **0.1 thousand** | **-4.7 thousand** | **-0.6 thousand** |

Notes: Welfare is the present discounted value of the entire stream of per-period payoffs over the period 2004-2013. Average annual welfare is welfare divided by the number of years. Counterfactual, actual, and Base scenario welfare are calculated using the parameter estimates from the structural model. Actual welfare is calculated using actual values of actions and states in the data. Counterfactual welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 under the assumption that no artificial recharge takes place. Base scenario welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual welfare values, Base scenario welfare values, the difference between counterfactual and actual welfare values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario welfare values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' welfare values and 'Counterfactual Minus Base Scenario' welfare values denote the significance level of the respective differences. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table 12: No Artificial Recharge Counterfactual Social Welfare, 2004-2013

| | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Producer Surplus Components | | | |
| Appropriator profits | -3.2 million | 0.7 million | 1.1 million |
| Farmer profits inside Beaumont Basin | 24.3 thousand | 1.5 thousand | -1.3 thousand |
| Farmer profits outside Beaumont Basin | 13.2 thousand | -1.2 thousand | -0.6 thousand |
| Recreational user profits | 0.1 thousand | -4.7 thousand | -0.6 thousand |
| **Total Producer Surplus** | **-3.2 million** | **0.68 million** | **1.06 million** |
| | *Average Annual Consumer Surplus (dollars)* | | |
| Beaumont-Cherry Valley Water District | 8.7 million | 0.9 million *** | 0 million *** |
| City of Banning | 7.9 million | 0.8 million *** | 0 million *** |
| South Mesa Water Company | 2.9 million | 0.3 million *** | 0 million *** |
| Yucaipa Valley Water District | 13.3 million | 1.3 million *** | 0 million *** |
| **Total Consumer Surplus** | **32.8 million** | **3.3 million *** ** | **0.1 million *** ** |
| | *Average Annual Value of Property Rights (dollars)* | | |
| Beaumont-Cherry Valley Water District | -11.4 thousand | -2.6 thousand | -1.6 thousand |
| City of Banning | -2.3 thousand | -0.1 thousand | 0.3 thousand |
| South Mesa Water Company | -4 thousand | -0.9 thousand | -0.7 thousand |
| Yucaipa Valley Water District | -4.3 thousand | -1 thousand | -0.6 thousand |
| Farmers inside Beaumont Basin | -1 thousand | -0.4 thousand | -0.3 thousand |
| Recreational Users | -3.3 thousand | -0.4 thousand | 0 thousand |
| **Total Value of Property Rights** | **0 million** | **0 million** | **0 million** |
| | *Average Annual Value of Imported Water (dollars)* | | |
| Beaumont-Cherry Valley Water District | 0 thousand | -784.7 thousand | -0.9 million |
| City of Banning | 0 thousand | -187.7 thousand | -0.2 million |
| South Mesa Water Company | N/A | N/A | N/A |
| Yucaipa Valley Water District | 1065.2 thousand | 96.1 thousand | 0 million |
| **Total Value of Imported Water** | **1.1 million** | **-876.3 thousand *** ** | **-1.1 million *** ** |
| **Social Welfare** | **30.7 million** | **3.1 million *** ** | **0.1 million** |

Notes: Components of social welfare are the present discounted value of the entire stream of per-period payoffs related to each component over the period 2004-2013. Average annual values of these components are equal to the total value of the component divided by the number of years. Producer surplus is equal to the sum of profits from groundwater extraction by each group of players, and the value of holding property rights for appropriators. Consumer surplus is equal to the sum of consumer surplus for each appropriator in the sample and is determined by the residential demand model. It is not weighted by parameters in the payoff function of the appropriator. Social welfare is equal to the sum of producer surplus and consumer surplus. Counterfactual, actual, and Base scenario values are calculated using the parameter estimates from the structural model. Actual values are calculated using actual values of actions and states in the data. Counterfactual values are calculated using model predicted actions and states generated from 100 simulation runs of the open access period. Base scenario values is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual values, Base scenario values, the difference between counterfactual and actual values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' values and 'Counterfactual Minus Base Scenario' values denote the significance level of the respective differences. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table 13: No Artificial Recharge Counterfactual: Simulation Statistics, 2004-2013

| | Appropriator inside Beaumont | Appropriator outside Beaumont | Farmer inside Beaumont | Farmer outside Beaumont | Golf Course / Housing Development | Appropriator Imported Water |
|---|---|---|---|---|---|---|
| | *Groundwater Extraction (acre-feet)* | | | | | *Artificial Recharge (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 3246.95 | 4745.39 | 404.32 | 218.92 | 519.03 | 0.00 |
| Std Dev | 3234.20 | 2687.20 | 331.77 | 218.92 | 433.18 | 0.00 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | -0.022 | 0.072 | 0.616 | 0.003 | -0.001 | -1.000 |
| Std Dev | 0.332 | 0.216 | 0.487 | 0.119 | 0.243 | 0.691 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | -0.040 | 0.077 | 0.488 | 0.000 | 0.000 | -0.997 |
| Std Dev | 0.332 | 0.216 | 0.487 | 0.119 | 0.243 | 0.691 |
| | *Depth to Groundwater (feet)* | | | | | *Filtered Sales (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 204.31 | 132.67 | 287.10 | 208.79 | 242.32 | 4765.54 |
| Std Dev | 50.04 | 37.19 | 83.36 | 208.79 | 87.82 | 2406.59 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | 0.089 | 0.005 | 0.004 | 0.006 | -0.002 | 0.002 |
| Std Dev | 0.092 | 0.044 | 0.024 | 0.064 | 0.035 | 0.150 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | 0.088 | 0.000 | 0.012 | 0.004 | 0.000 | 0.000 |
| Std Dev | 0.092 | 0.044 | 0.024 | 0.064 | 0.035 | 0.150 |

Notes: This table compares the counterfactual actions and states with the actual and Base scenario actions and states.

Table 14: No Filtered Water Sales Counterfactual: Average Annual Welfare, 2004-2013

| Player | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Appropriator Profits | | | |
| Beaumont-Cherry Valley Water District | -1.3 million | -0.1 million | 0 million |
| City of Banning | -0.2 million | -0.1 million | 0 million |
| South Mesa Water Company | 0 million | 0 million | 0 million |
| Yucaipa Valley Water District | -2.5 million | 1.5 million * | 1.7 million ** |
| **Total appropriators** | **-3.9 million** | **1.4 million** | **1.7 million** |
| | | *Average Annual Welfare (dollars)* | |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | 8 million | 0.8 million | 0 million |
| City of Banning | 7.1 million | 0.7 million | 0 million |
| South Mesa Water Company | 1.8 million | 0.2 million | 0 million |
| Yucaipa Valley Water District | 14.4 million | 1.4 million | 0 million |
| **Total appropriators** | **31.4 million** | **3.1 million** | **0 million** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 18.9 thousand | 2 thousand | 0 thousand |
| Riedman | 6.8 thousand | 0.9 thousand | 0.1 thousand |
| **Total farmers in Beaumont Basin** | **25.7 thousand** | **2.8 thousand** | **0.1 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | 0.8 thousand | -0.3 thousand | 0 thousand |
| Illy | 4.5 thousand | 0.2 thousand | -0.1 thousand |
| Summit Cemetery District | -0.2 thousand | -1.6 thousand | -0.2 thousand |
| Hudson | 7.6 thousand | 0.1 thousand | -0.8 thousand |
| **Total farmers outside Beaumont Basin** | **12.7 thousand** | **-1.7 thousand** | **-1.1 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | -19 thousand | 3.5 thousand | 0.1 thousand |
| Southern California PGA | 19.9 thousand | -7.7 thousand | -0.6 thousand |
| Oak Valley Partners | 0.2 thousand | 0.3 thousand | 0.1 thousand |
| Plantation on the Lake | -0.5 thousand | -0.5 thousand | -0.1 thousand |
| Sharondale Mesa Owners Association | -0.5 thousand | -0.2 thousand | -0.1 thousand |
| **Total recreational users** | **0.1 thousand** | **-4.7 thousand** | **-0.7 thousand** |

Notes: Welfare is the present discounted value of the entire stream of per-period payoffs over the period 2004-2013. Average annual welfare is welfare divided by the number of years. Counterfactual, actual, and Base scenario welfare are calculated using the parameter estimates from the structural model. Actual welfare is calculated using actual values of actions and states in the data. Counterfactual welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 under the assumption that no filtered water sales take place. Base scenario welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual welfare values, Base scenario welfare values, the difference between counterfactual and actual welfare values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario welfare values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' welfare values and 'Counterfactual Minus Base Scenario' welfare values denote the significance level of the respective differences. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table 15: No Filtered Sales Counterfactual Social Welfare, 2004-2013

| | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Producer Surplus Components | | | |
| Appropriator profits | -2.6 million | 1.4 million | 1.7 million |
| Farmer profits inside Beaumont Basin | 25.7 thousand | 2.8 thousand | 0.1 thousand |
| Farmer profits outside Beaumont Basin | 12.7 thousand | -1.7 thousand | -1.1 thousand |
| Recreational user profits | 0.1 thousand | -4.7 thousand | -0.7 thousand |
| **Total Producer Surplus** | **-2.53 million** | **1.36 million** | **1.73 million** |
| | *Average Annual Consumer Surplus (dollars)* | | |
| Beaumont-Cherry Valley Water District | 8.7 million | 0.9 million *** | 0 million ** |
| City of Banning | 7.9 million | 0.8 million *** | 0 million |
| South Mesa Water Company | 2.8 million | 0.2 million *** | 0 million |
| Yucaipa Valley Water District | 12.9 million | 0.9 million *** | -0.3 million *** |
| **Total Consumer Surplus** | **32.4 million** | **2.9 million *** ** | **-0.3 million *** ** |
| | *Average Annual Value of Property Rights (dollars)* | | |
| Beaumont-Cherry Valley Water District | -9.8 thousand | -1 thousand | 0 thousand |
| City of Banning | -2.7 thousand | -0.4 thousand | 0 thousand |
| South Mesa Water Company | -3.3 thousand | -0.2 thousand | 0 thousand |
| Yucaipa Valley Water District | -5.6 thousand | -2.3 thousand | -1.9 thousand |
| Farmers inside Beaumont Basin | -0.8 thousand | -0.1 thousand | 0 thousand |
| Recreational Users | -3.4 thousand | -0.4 thousand | 0 thousand |
| **Total Value of Property Rights** | **0 million** | **0 million** | **0 million** |
| | *Average Annual Value of Imported Water (dollars)* | | |
| Beaumont-Cherry Valley Water District | 847.6 thousand | 62.9 thousand | 0 million |
| City of Banning | 211.7 thousand | 24 thousand | 0 million |
| South Mesa Water Company | N/A | N/A | N/A |
| Yucaipa Valley Water District | 0 thousand | -969.1 thousand | -1.1 million |
| **Total Value of Imported Water** | **1.1 million** | **-882.1 thousand *** ** | **-1.1 million *** ** |
| **Social Welfare** | **30.9 million** | **3.3 million *** ** | **0.3 million *** ** |

Notes: Components of social welfare are the present discounted value of the entire stream of per-period payoffs related to each component over the period 2004-2013. Average annual values of these components are equal to the total value of the component divided by the number of years. Producer surplus is equal to the sum of profits from groundwater extraction by each group of players, and the value of holding property rights for appropriators. Consumer surplus is equal to the sum of consumer surplus for each appropriator in the sample and is determined by the residential demand model. It is not weighted by parameters in the payoff function of the appropriator. Social welfare is equal to the sum of producer surplus and consumer surplus. Counterfactual, actual, and Base scenario values are calculated using the parameter estimates from the structural model. Actual values are calculated using actual values of actions and states in the data. Counterfactual values are calculated using model predicted actions and states generated from 100 simulation runs of the open access period. Base scenario values is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual values, Base scenario values, the difference between counterfactual and actual values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' values and 'Counterfactual Minus Base Scenario' values denote the significance level of the respective differences. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table 16: No Filtered Sales Counterfactual: Simulation Statistics, 2004-2013

| | Appropriator inside Beaumont | Appropriator outside Beaumont | Farmer inside Beaumont | Farmer outside Beaumont | Golf Course / Housing Development | Appropriator Imported Water |
|---|---|---|---|---|---|---|
| | *Groundwater Extraction (acre-feet)* | | | | | *Artificial Recharge (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 3508.30 | 4959.51 | 275.21 | 222.87 | 519.39 | 3591.12 |
| Std Dev | 3416.99 | 3337.64 | 380.33 | 222.87 | 432.83 | 2341.42 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | 0.057 | 0.120 | 0.124 | 0.021 | 0.000 | -0.011 |
| Std Dev | 0.230 | 0.292 | 0.301 | 0.120 | 0.237 | 0.325 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | 0.038 | 0.126 | -0.003 | 0.018 | 0.001 | -0.008 |
| Std Dev | 0.230 | 0.292 | 0.301 | 0.120 | 0.237 | 0.325 |
| | *Depth to Groundwater (feet)* | | | | | *Filtered Sales (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 187.93 | 132.95 | 284.09 | 213.04 | 241.98 | 0.00 |
| Std Dev | 48.56 | 37.37 | 84.79 | 213.04 | 87.31 | 0.00 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | 0.002 | 0.007 | -0.007 | 0.026 | -0.003 | -1.000 |
| Std Dev | 0.048 | 0.045 | 0.015 | 0.067 | 0.035 | 0.467 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | 0.001 | 0.003 | 0.001 | 0.024 | -0.001 | -1.002 |
| Std Dev | 0.048 | 0.045 | 0.015 | 0.067 | 0.035 | 0.467 |

Notes: This table compares the counterfactual actions and states with the actual and Base scenario actions and states.

Table 17: No Property Rights Trading Counterfactual: Average Annual Welfare, 2004-2013

| Player | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Appropriator Profits | | | |
| Beaumont-Cherry Valley Water District | -1.3 million | -0.3 million | -0.2 million |
| City of Banning | -0.2 million | -0.1 million | 0 million |
| South Mesa Water Company | 0 million | 0 million | 0 million |
| Yucaipa Valley Water District | -2.5 million | -0.2 million | 0 million |
| **Total appropriators** | **-3.9 million** | **-0.5 million** | **-0.2 million** |
| | | *Average Annual Welfare (dollars)* | |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | 8 million | 0.8 million | 0 million |
| City of Banning | 7.1 million | 0.7 million | 0 million |
| South Mesa Water Company | 1.8 million | 0.2 million | 0 million |
| Yucaipa Valley Water District | 14.4 million | 1.4 million | 0 million |
| **Total appropriators** | **31.4 million** | **3.1 million** | **0 million** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 18.7 thousand | 1.8 thousand | -0.2 thousand |
| Riedman | 6.8 thousand | 0.9 thousand | 0.1 thousand |
| **Total farmers in Beaumont Basin** | **25.5 thousand** | **2.7 thousand** | **0 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | 0.7 thousand | -0.3 thousand | 0 thousand |
| Illy | 4.7 thousand | 0.4 thousand | 0.1 thousand |
| Summit Cemetery District | -0.2 thousand | -1.6 thousand | -0.2 thousand |
| Hudson | 8.4 thousand | 0.8 thousand | 0 thousand |
| **Total farmers outside Beaumont Basin** | **13.6 thousand** | **-0.7 thousand** | **-0.1 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | -18.7 thousand | 3.8 thousand | 0.4 thousand |
| Southern California PGA | 21.8 thousand | -5.8 thousand | 1.3 thousand |
| Oak Valley Partners | 0.1 thousand | 0.1 thousand | -0.1 thousand |
| Plantation on the Lake | -0.3 thousand | -0.3 thousand | 0.1 thousand |
| Sharondale Mesa Owners Association | -0.3 thousand | -0.1 thousand | 0.1 thousand |
| **Total recreational users** | **2.6 thousand** | **-2.2 thousand** | **1.8 thousand** |

Notes: Welfare is the present discounted value of the entire stream of per-period payoffs over the period 2004-2013. Average annual welfare is welfare divided by the number of years. Counterfactual, actual, and Base scenario welfare are calculated using the parameter estimates from the structural model. Actual welfare is calculated using actual values of actions and states in the data. Counterfactual welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 under the assumption that no property rights trading takes place. Base scenario welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual welfare values, Base scenario welfare values, the difference between counterfactual and actual welfare values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario welfare values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' welfare values and 'Counterfactual Minus Base Scenario' welfare values denote the significance level of the respective differences. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table 18: No Property Rights Trading Counterfactual Social Welfare, 2004-2013

| | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Producer Surplus Components | | | |
| Appropriator profits | -4.5 million | -0.5 million | -0.2 million |
| Farmer profits inside Beaumont Basin | 25.5 thousand | 2.7 thousand | 0 thousand |
| Farmer profits outside Beaumont Basin | 13.6 thousand | -0.7 thousand | -0.1 thousand |
| Recreational user profits | 2.6 thousand | -2.2 thousand | 1.8 thousand |
| **Total Producer Surplus** | **-4.43 million** | **-0.54 million** | **-0.17 million** |
| | *Average Annual Consumer Surplus (dollars)* | | |
| Beaumont-Cherry Valley Water District | 8.7 million | 0.9 million *** | 0 million *** |
| City of Banning | 7.9 million | 0.8 million *** | 0 million *** |
| South Mesa Water Company | 2.9 million | 0.3 million *** | 0 million *** |
| Yucaipa Valley Water District | 13.3 million | 1.3 million *** | 0 million |
| **Total Consumer Surplus** | **32.7 million** | **3.2 million *** ** | **0 million ** ** |
| | *Average Annual Value of Property Rights (dollars)* | | |
| Beaumont-Cherry Valley Water District | -9.6 thousand | -0.8 thousand | 0.2 thousand |
| City of Banning | -2.6 thousand | -0.3 thousand | 0.1 thousand |
| South Mesa Water Company | -2.7 thousand | 0.4 thousand | 0.5 thousand |
| Yucaipa Valley Water District | -3.7 thousand | -0.4 thousand | 0 thousand |
| Farmers inside Beaumont Basin | -0.7 thousand | -0.1 thousand | 0 thousand |
| Recreational Users | -3.3 thousand | -0.3 thousand | 0.1 thousand |
| **Total Value of Property Rights** | **0 million** | **0 million** | **0 million** |
| | *Average Annual Value of Imported Water (dollars)* | | |
| Beaumont-Cherry Valley Water District | 1021.7 thousand | 237 thousand ** | 0.2 million * |
| City of Banning | 211.8 thousand | 24.2 thousand | 0 million |
| South Mesa Water Company | N/A | N/A | N/A |
| Yucaipa Valley Water District | 1060.6 thousand | 91.5 thousand | 0 million |
| **Total Value of Imported Water** | **2.3 million** | **352.7 thousand *** | **0.2 million** |
| **Social Welfare** | **30.6 million** | **3 million *** ** | **0 million** |

Notes: Components of social welfare are the present discounted value of the entire stream of per-period payoffs related to each component over the period 2004-2013. Average annual values of these components are equal to the total value of the component divided by the number of years. Producer surplus is equal to the sum of profits from groundwater extraction by each group of players, and the value of holding property rights for appropriators. Consumer surplus is equal to the sum of consumer surplus for each appropriator in the sample and is determined by the residential demand model. It is not weighted by parameters in the payoff function of the appropriator. Social welfare is equal to the sum of producer surplus and consumer surplus. Counterfactual, actual, and Base scenario values are calculated using the parameter estimates from the structural model. Actual values are calculated using actual values of actions and states in the data. Counterfactual values are calculated using model predicted actions and states generated from 100 simulation runs of the open access period. Base scenario values is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual values, Base scenario values, the difference between counterfactual and actual values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' values and 'Counterfactual Minus Base Scenario' values denote the significance level of the respective differences. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table 19: No Property Rights Trading Counterfactual: Simulation Statistics, 2004-2013

| | Appropriator inside Beaumont | Appropriator outside Beaumont | Farmer inside Beaumont | Farmer outside Beaumont | Golf Course / Housing Development | Appropriator Imported Water |
|---|---|---|---|---|---|---|
| | | | *Groundwater Extraction (acre-feet)* | | | *Artificial Recharge (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 3292.20 | 4473.44 | 256.23 | 218.66 | 518.44 | 4106.36 |
| Std Dev | 3303.00 | 2671.15 | 386.78 | 218.66 | 436.12 | 2611.93 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | -0.008 | 0.011 | 0.047 | 0.001 | -0.002 | 0.131 |
| Std Dev | 0.200 | 0.156 | 0.301 | 0.119 | 0.238 | 0.469 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | -0.027 | 0.016 | -0.080 | -0.001 | -0.001 | 0.134 |
| Std Dev | 0.200 | 0.156 | 0.301 | 0.119 | 0.238 | 0.469 |
| | | | *Depth to Groundwater (feet)* | | | *Filtered Sales (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 184.73 | 132.80 | 283.51 | 208.12 | 241.87 | 4749.14 |
| Std Dev | 49.12 | 37.23 | 85.23 | 208.12 | 87.05 | 2427.03 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | -0.015 | 0.006 | -0.009 | 0.003 | -0.004 | -0.001 |
| Std Dev | 0.051 | 0.045 | 0.015 | 0.061 | 0.034 | 0.154 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | -0.016 | 0.001 | -0.001 | 0.001 | -0.001 | -0.003 |
| Std Dev | 0.051 | 0.045 | 0.015 | 0.061 | 0.034 | 0.154 |

Notes: This table compares the counterfactual actions and states with the actual and Base scenario actions and states.

Table 20: No Imported Water Counterfactual: Average Annual Welfare, 2004-2013

| Player | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Appropriator Profits | | | |
| Beaumont-Cherry Valley Water District | -1.3 million | 0.8 million *** | 1 million *** |
| City of Banning | -0.2 million | 0.1 million | 0.2 million * |
| South Mesa Water Company | 0 million | 0 million | -0.1 million |
| Yucaipa Valley Water District | -2.5 million | 1.4 million * | 1.6 million ** |
| **Total appropriators** | **-3.9 million** | **2.4 million *** | **2.7 million** |
| | | *Average Annual Welfare (dollars)* | |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | 8.2 million | 0.9 million | 0.1 million |
| City of Banning | 7.1 million | 0.7 million | 0 million |
| South Mesa Water Company | 1.8 million | 0.2 million | 0 million |
| Yucaipa Valley Water District | 14.4 million | 1.4 million | 0 million |
| **Total appropriators** | **31.6 million** | **3.2 million** | **0.1 million** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 20.2 thousand | 3.3 thousand | 1.3 thousand |
| Riedman | 4.2 thousand | -1.7 thousand | -2.5 thousand |
| **Total farmers in Beaumont Basin** | **24.4 thousand** | **1.6 thousand** | **-1.2 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | 0.7 thousand | -0.3 thousand | 0 thousand |
| Illy | 4.5 thousand | 0.1 thousand | -0.2 thousand |
| Summit Cemetery District | -0.7 thousand | -2.1 thousand * | -0.7 thousand |
| Hudson | 7.7 thousand | 0.1 thousand | -0.8 thousand |
| **Total farmers outside Beaumont Basin** | **12.1 thousand** | **-2.2 thousand** | **-1.6 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | -20.1 thousand | 2.4 thousand | -1 thousand |
| Southern California PGA | 19.9 thousand | -7.8 thousand | -0.6 thousand |
| Oak Valley Partners | 0.1 thousand | 0.2 thousand | 0 thousand |
| Plantation on the Lake | -0.4 thousand | -0.4 thousand | 0 thousand |
| Sharondale Mesa Owners Association | -0.5 thousand | -0.3 thousand | -0.1 thousand |
| **Total recreational users** | **-1 thousand** | **-5.8 thousand** | **-1.8 thousand** |

Notes: Welfare is the present discounted value of the entire stream of per-period payoffs over the period 2004-2013. Average annual welfare is welfare divided by the number of years. Counterfactual, actual, and Base scenario welfare are calculated using the parameter estimates from the structural model. Actual welfare is calculated using actual values of actions and states in the data. Counterfactual welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 under the assumption that there is no imported water. Base scenario welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual welfare values, Base scenario welfare values, the difference between counterfactual and actual welfare values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario welfare values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' welfare values and 'Counterfactual Minus Base Scenario' welfare values denote the significance level of the respective differences. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table 21: No Imported Water Counterfactual Social Welfare, 2004-2013

| | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Producer Surplus Components | | | |
| Appropriator profits | -1.6 million | 2.4 million * | 2.7 million ** |
| Farmer profits inside Beaumont Basin | 24.4 thousand | 1.6 thousand | -1.2 thousand |
| Farmer profits outside Beaumont Basin | 12.1 thousand | -2.2 thousand | -1.6 thousand |
| Recreational user profits | -1 thousand | -5.8 thousand | -1.8 thousand |
| **Total Producer Surplus** | **-1.53 million** | **2.36 million** | **2.73 million** |
| | *Average Annual Consumer Surplus (dollars)* | | |
| Beaumont-Cherry Valley Water District | 8.7 million | 0.9 million *** | 0 million *** |
| City of Banning | 7.9 million | 0.8 million *** | 0 million *** |
| South Mesa Water Company | 2.9 million | 0.3 million *** | 0.1 million *** |
| Yucaipa Valley Water District | 13 million | 1 million *** | -0.3 million *** |
| **Total Consumer Surplus** | **32.5 million** | **3 million *** ** | **-0.2 million *** ** |
| | *Average Annual Value of Property Rights (dollars)* | | |
| Beaumont-Cherry Valley Water District | -11.4 thousand | -2.6 thousand | -1.6 thousand |
| City of Banning | -2.3 thousand | -0.1 thousand | 0.3 thousand |
| South Mesa Water Company | -4 thousand | -0.9 thousand | -0.8 thousand |
| Yucaipa Valley Water District | -6.8 thousand | -3.5 thousand | -3.1 thousand |
| Farmers inside Beaumont Basin | -1 thousand | -0.4 thousand | -0.3 thousand |
| Recreational Users | -3.3 thousand | -0.4 thousand | 0 thousand |
| **Total Value of Property Rights** | **0 million** | **0 million** | **0 million** |
| | *Average Annual Value of Imported Water (dollars)* | | |
| Beaumont-Cherry Valley Water District | 0 thousand | -784.7 thousand | -0.9 million |
| City of Banning | 0 thousand | -187.7 thousand | -0.2 million |
| South Mesa Water Company | N/A | N/A | N/A |
| Yucaipa Valley Water District | 0 thousand | -969.1 thousand | -1.1 million |
| **Total Value of Imported Water** | **0 million** | **-1941.4 thousand** | **-2.1 million** |
| **Social Welfare** | **31 million** | **3.4 million *** ** | **0.4 million ** ** |

Notes: Components of social welfare are the present discounted value of the entire stream of per-period payoffs related to each component over the period 2004-2013. Average annual values of these components are equal to the total value of the component divided by the number of years. Producer surplus is equal to the sum of profits from groundwater extraction by each group of players, and the value of holding property rights for appropriators. Consumer surplus is equal to the sum of consumer surplus for each appropriator in the sample and is determined by the residential demand model. It is not weighted by parameters in the payoff function of the appropriator. Social welfare is equal to the sum of producer surplus and consumer surplus. Counterfactual, actual, and Base scenario values are calculated using the parameter estimates from the structural model. Actual values are calculated using actual values of actions and states in the data. Counterfactual values are calculated using model predicted actions and states generated from 100 simulation runs of the open access period. Base scenario values is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual values, Base scenario values, the difference between counterfactual and actual values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' values and 'Counterfactual Minus Base Scenario' values denote the significance level of the respective differences. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table 22: No Imported Water Counterfactual: Simulation Statistics, 2004-2013

| | Appropriator inside Beaumont | Appropriator outside Beaumont | Farmer inside Beaumont | Farmer outside Beaumont | Golf Course / Housing Development | Appropriator Imported Water |
|---|---|---|---|---|---|---|
| | *Groundwater Extraction (acre-feet)* | | | | | *Artificial Recharge (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 3397.53 | 5296.87 | 404.47 | 222.29 | 519.47 | 0.00 |
| Std Dev | 3164.85 | 3236.50 | 332.34 | 222.29 | 434.48 | 0.00 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | 0.023 | 0.197 | 0.616 | 0.018 | 0.000 | -1.000 |
| Std Dev | 0.370 | 0.296 | 0.494 | 0.120 | 0.237 | 0.691 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | 0.005 | 0.202 | 0.488 | 0.016 | 0.001 | -0.997 |
| Std Dev | 0.370 | 0.296 | 0.494 | 0.120 | 0.237 | 0.691 |
| | *Depth to Groundwater (feet)* | | | | | *Filtered Water (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 204.42 | 132.74 | 286.98 | 213.52 | 242.39 | 0.00 |
| Std Dev | 49.85 | 37.17 | 83.18 | 213.52 | 88.18 | 0.00 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | 0.090 | 0.005 | 0.003 | 0.029 | -0.002 | -1.000 |
| Std Dev | 0.092 | 0.045 | 0.024 | 0.071 | 0.035 | 0.467 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | 0.089 | 0.001 | 0.011 | 0.027 | 0.001 | -1.002 |
| Std Dev | 0.092 | 0.045 | 0.024 | 0.071 | 0.035 | 0.467 |

Notes: This table compares the counterfactual actions and states with the actual and Base scenario actions and states.

Table 23: No Imports or Trading Counterfactual: Average Annual Welfare, 2004-2013

| | *Average Annual Welfare (dollars)* | | |
|---|---|---|---|
| Player | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
| Appropriator Profits | | | |
| Beaumont-Cherry Valley Water District | -1.3 million | 0.8 million *** | 1 million *** |
| City of Banning | -0.2 million | 0.1 million | 0.2 million * |
| South Mesa Water Company | 0 million | -0.1 million | -0.1 million |
| Yucaipa Valley Water District | -2.5 million | 1.4 million * | 1.6 million ** |
| **Total appropriators** | **-3.9 million** | **2.3 million *** | **2.7 million** |
| | *Average Annual Welfare (dollars)* | | |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | 8.1 million | 0.9 million | 0.1 million |
| City of Banning | 7.1 million | 0.7 million | 0 million |
| South Mesa Water Company | 1.8 million | 0.1 million | 0 million |
| Yucaipa Valley Water District | 14.4 million | 1.4 million | 0 million |
| **Total appropriators** | **31.5 million** | **3.2 million** | **0.1 million** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 20.2 thousand | 3.3 thousand | 1.3 thousand |
| Riedman | 4.2 thousand | -1.7 thousand | -2.5 thousand |
| **Total farmers in Beaumont Basin** | **24.4 thousand** | **1.6 thousand** | **-1.2 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | 0.7 thousand | -0.3 thousand | 0 thousand |
| Illy | 4.5 thousand | 0.1 thousand | -0.2 thousand |
| Summit Cemetery District | -0.7 thousand | -2.1 thousand * | -0.7 thousand |
| Hudson | 7.7 thousand | 0.1 thousand | -0.7 thousand |
| **Total farmers outside Beaumont Basin** | **12.2 thousand** | **-2.2 thousand** | **-1.6 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | -20 thousand | 2.5 thousand | -1 thousand |
| Southern California PGA | 19.9 thousand | -7.8 thousand | -0.6 thousand |
| Oak Valley Partners | 0.1 thousand | 0.2 thousand | 0 thousand |
| Plantation on the Lake | -0.4 thousand | -0.4 thousand | 0 thousand |
| Sharondale Mesa Owners Association | -0.5 thousand | -0.3 thousand | -0.1 thousand |
| **Total recreational users** | **-1 thousand** | **-5.8 thousand** | **-1.7 thousand** |

Notes: Welfare is the present discounted value of the entire stream of per-period payoffs over the period 2004-2013. Average annual welfare is welfare divided by the number of years. Counterfactual, actual, and Base scenario welfare are calculated using the parameter estimates from the structural model. Actual welfare is calculated using actual values of actions and states in the data. Counterfactual welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 under the assumption that there is no imported water or property rights trading. Base scenario welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual welfare values, Base scenario welfare values, the difference between counterfactual and actual welfare values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario welfare values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' welfare values and 'Counterfactual Minus Base Scenario' welfare values denote the significance level of the respective differences. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table 24: No Imports or Trading Counterfactual Social Welfare, 2004-2013

| | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Producer Surplus Components | | | |
| Appropriator profits | -1.6 million | 2.3 million * | 2.7 million ** |
| Farmer profits inside Beaumont Basin | 24.4 thousand | 1.6 thousand | -1.2 thousand |
| Farmer profits outside Beaumont Basin | 12.2 thousand | -2.2 thousand | -1.6 thousand |
| Recreational user profits | -1 thousand | -5.8 thousand | -1.7 thousand |
| **Total Producer Surplus** | **-1.56 million** | **2.32 million** | **2.7 million** |
| | *Average Annual Consumer Surplus (dollars)* | | |
| Beaumont-Cherry Valley Water District | 8.7 million | 0.9 million *** | 0 million *** |
| City of Banning | 7.9 million | 0.8 million *** | 0 million *** |
| South Mesa Water Company | 2.9 million | 0.3 million *** | 0.1 million *** |
| Yucaipa Valley Water District | 13 million | 1 million *** | -0.3 million *** |
| **Total Consumer Surplus** | **32.6 million** | **3 million *** ** | **-0.2 million *** ** |
| | *Average Annual Value of Property Rights (dollars)* | | |
| Beaumont-Cherry Valley Water District | -11.7 thousand | -2.9 thousand | -1.8 thousand |
| City of Banning | -2.3 thousand | 0 thousand | 0.4 thousand |
| South Mesa Water Company | -3.2 thousand | -0.1 thousand | 0 thousand |
| Yucaipa Valley Water District | -6.8 thousand | -3.5 thousand | -3.1 thousand |
| Farmers inside Beaumont Basin | -1 thousand | -0.4 thousand | -0.3 thousand |
| Recreational Users | -3.3 thousand | -0.4 thousand | 0 thousand |
| **Total Value of Property Rights** | **0 million** | **0 million** | **0 million** |
| | *Average Annual Value of Imported Water (dollars)* | | |
| Beaumont-Cherry Valley Water District | 0 thousand | -784.7 thousand | -0.9 million |
| City of Banning | 0 thousand | -187.7 thousand | -0.2 million |
| South Mesa Water Company | N/A | N/A | N/A |
| Yucaipa Valley Water District | 0 thousand | -969.1 thousand | -1.1 million |
| **Total Value of Imported Water** | **0 million** | **-1941.4 thousand** | **-2.1 million** |
| **Social Welfare** | **31 million** | **3.4 million *** ** | **0.4 million ** ** |

Notes: Components of social welfare are the present discounted value of the entire stream of per-period payoffs related to each component over the period 2004-2013. Average annual values of these components are equal to the total value of the component divided by the number of years. Producer surplus is equal to the sum of profits from groundwater extraction by each group of players, and the value of holding property rights for appropriators. Consumer surplus is equal to the sum of consumer surplus for each appropriator in the sample and is determined by the residential demand model. It is not weighted by parameters in the payoff function of the appropriator. Social welfare is equal to the sum of producer surplus and consumer surplus. Counterfactual, actual, and Base scenario values are calculated using the parameter estimates from the structural model. Actual values are calculated using actual values of actions and states in the data. Counterfactual values are calculated using model predicted actions and states generated from 100 simulation runs of the open access period. Base scenario values is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual values, Base scenario values, the difference between counterfactual and actual values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' values and 'Counterfactual Minus Base Scenario' values denote the significance level of the respective differences. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table 25: No Imports or Trading Counterfactual: Simulation Statistics, 2004-2013

| | Appropriator inside Beaumont | Appropriator outside Beaumont | Farmer inside Beaumont | Farmer outside Beaumont | Golf Course / Housing Development | Appropriator Imported Water |
|---|---|---|---|---|---|---|
| | | | *Groundwater Extraction (acre-feet)* | | | *Artificial Recharge (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 3268.26 | 5455.53 | 404.47 | 222.16 | 519.31 | 0.00 |
| Std Dev | 2869.79 | 3177.08 | 332.34 | 222.16 | 434.44 | 0.00 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | -0.016 | 0.232 | 0.616 | 0.017 | 0.000 | -1.000 |
| Std Dev | 0.432 | 0.317 | 0.494 | 0.119 | 0.237 | 0.691 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | -0.034 | 0.238 | 0.488 | 0.015 | 0.001 | -0.997 |
| Std Dev | 0.432 | 0.317 | 0.494 | 0.119 | 0.237 | 0.691 |
| | | | *Depth to Groundwater (feet)* | | | *Filtered Water (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 204.42 | 132.74 | 286.98 | 213.39 | 242.31 | 0.00 |
| Std Dev | 49.85 | 37.17 | 83.18 | 213.39 | 88.03 | 0.00 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | 0.090 | 0.005 | 0.003 | 0.028 | -0.002 | -1.000 |
| Std Dev | 0.092 | 0.045 | 0.024 | 0.070 | 0.035 | 0.467 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | 0.089 | 0.001 | 0.011 | 0.026 | 0.000 | -1.002 |
| Std Dev | 0.092 | 0.045 | 0.024 | 0.070 | 0.035 | 0.467 |

Notes: This table compares the counterfactual actions and states with the actual and Base scenario actions and states.

Table 26: Equal Initial Property Right Allocation Counterfactual: Average Annual Welfare, 2004-2013

| Player | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Appropriator Profits | | | |
| Beaumont-Cherry Valley Water District | -1.3 million | -0.2 million | 0 million |
| City of Banning | -0.2 million | 0 million | 0.1 million |
| South Mesa Water Company | 0 million | -0.1 million | -0.2 million |
| Yucaipa Valley Water District | -2.5 million | -0.3 million | -0.1 million |
| **Total appropriators** | **-3.9 million** | **-0.6 million** | **-0.3 million** |
| | | *Average Annual Welfare (dollars)* | |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | 8 million | 0.8 million | 0 million |
| City of Banning | 7.1 million | 0.7 million | 0 million |
| South Mesa Water Company | 1.8 million | 0.1 million | -0.1 million |
| Yucaipa Valley Water District | 14.4 million | 1.4 million | 0 million |
| **Total appropriators** | **31.4 million** | **3 million** | **0 million** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 19.1 thousand | 2.2 thousand | 0.2 thousand |
| Riedman | 6.9 thousand | 1 thousand | 0.2 thousand |
| **Total farmers in Beaumont Basin** | **26 thousand** | **3.2 thousand** | **0.4 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | 0.8 thousand | -0.3 thousand | 0 thousand |
| Illy | 4.7 thousand | 0.3 thousand | 0 thousand |
| Summit Cemetery District | -0.4 thousand | -1.8 thousand | -0.4 thousand |
| Hudson | 8.5 thousand | 1 thousand | 0.1 thousand |
| **Total farmers outside Beaumont Basin** | **13.6 thousand** | **-0.8 thousand** | **-0.2 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | -19 thousand | 3.5 thousand | 0.1 thousand |
| Southern California PGA | 20.9 thousand | -6.8 thousand | 0.4 thousand |
| Oak Valley Partners | 0 thousand | 0.1 thousand | -0.1 thousand |
| Plantation on the Lake | -0.4 thousand | -0.4 thousand | 0 thousand |
| Sharondale Mesa Owners Association | -0.5 thousand | -0.2 thousand | -0.1 thousand |
| **Total recreational users** | **1 thousand** | **-3.8 thousand** | **0.2 thousand** |

Notes: Welfare is the present discounted value of the entire stream of per-period payoffs over the period 2004-2013. Average annual welfare is welfare divided by the number of years. Counterfactual, actual, and Base scenario welfare are calculated using the parameter estimates from the structural model. Actual welfare is calculated using actual values of actions and states in the data. Counterfactual welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 under the assumption of equal initial property right allocations. Base scenario welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual welfare values, Base scenario welfare values, the difference between counterfactual and actual welfare values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario welfare values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' welfare values and 'Counterfactual Minus Base Scenario' welfare values denote the significance level of the respective differences. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table 27: Equal Initial Property Right Allocation Counterfactual Social Welfare, 2004-2013

| | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Producer Surplus Components | | | |
| Appropriator profits | -4.6 million | -0.6 million | -0.3 million |
| Farmer profits inside Beaumont Basin | 26 thousand | 3.2 thousand | 0.4 thousand |
| Farmer profits outside Beaumont Basin | 13.6 thousand | -0.8 thousand | -0.2 thousand |
| Recreational user profits | 1 thousand | -3.8 thousand | 0.2 thousand |
| **Total Producer Surplus** | **-4.53 million** | **-0.64 million** | **-0.27 million** |
| | *Average Annual Consumer Surplus (dollars)* | | |
| Beaumont-Cherry Valley Water District | 8.7 million | 0.9 million *** | 0 million * |
| City of Banning | 7.9 million | 0.8 million *** | 0 million *** |
| South Mesa Water Company | 3 million | 0.4 million *** | 0.1 million *** |
| Yucaipa Valley Water District | 13.3 million | 1.4 million *** | 0.1 million *** |
| **Total Consumer Surplus** | **32.9 million** | **3.4 million *** ** | **0.2 million *** ** |
| | *Average Annual Value of Property Rights (dollars)* | | |
| Beaumont-Cherry Valley Water District | -8.6 thousand | 0.1 thousand | 1.2 thousand |
| City of Banning | -2 thousand | 0.2 thousand | 0.6 thousand |
| South Mesa Water Company | -2.7 thousand | 0.4 thousand | 0.6 thousand |
| Yucaipa Valley Water District | -4.8 thousand | -1.5 thousand | -1.1 thousand |
| Farmers inside Beaumont Basin | -0.8 thousand | -0.1 thousand | 0 thousand |
| Recreational Users | -3.3 thousand | -0.4 thousand | 0 thousand |
| **Total Value of Property Rights** | **0 million** | **0 million** | **0 million** |
| | *Average Annual Value of Imported Water (dollars)* | | |
| Beaumont-Cherry Valley Water District | 896.9 thousand | 112.2 thousand | 0 million |
| City of Banning | 210.4 thousand | 22.7 thousand | 0 million |
| South Mesa Water Company | N/A | N/A | N/A |
| Yucaipa Valley Water District | 1054.3 thousand | 85.2 thousand | 0 million |
| **Total Value of Imported Water** | **2.2 million** | **220.1 thousand** | **0 million** |
| **Social Welfare** | **30.5 million** | **2.9 million *** ** | **-0.1 million** |

Notes: Components of social welfare are the present discounted value of the entire stream of per-period payoffs related to each component over the period 2004-2013. Average annual values of these components are equal to the total value of the component divided by the number of years. Producer surplus is equal to the sum of profits from groundwater extraction by each group of players, and the value of holding property rights for appropriators. Consumer surplus is equal to the sum of consumer surplus for each appropriator in the sample and is determined by the residential demand model. It is not weighted by parameters in the payoff function of the appropriator. Social welfare is equal to the sum of producer surplus and consumer surplus. Counterfactual, actual, and Base scenario values are calculated using the parameter estimates from the structural model. Actual values are calculated using actual values of actions and states in the data. Counterfactual values are calculated using model predicted actions and states generated from 100 simulation runs of the open access period. Base scenario values is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual values, Base scenario values, the difference between counterfactual and actual values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' values and 'Counterfactual Minus Base Scenario' values denote the significance level of the respective differences. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table 28: Equal Initial Property Right Allocation: Simulation Statistics, 2004-2013

| | Appropriator inside Beaumont | Appropriator outside Beaumont | Farmer inside Beaumont | Farmer outside Beaumont | Golf Course / Housing Development | Appropriator Imported Water |
|---|---|---|---|---|---|---|
| | *Groundwater Extraction (acre-feet)* | | | | | *Artificial Recharge (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 3028.82 | 4831.05 | 275.99 | 218.74 | 515.99 | 3706.30 |
| Std Dev | 2359.95 | 2310.14 | 380.16 | 218.74 | 431.30 | 2338.45 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | -0.088 | 0.091 | 0.128 | 0.002 | -0.006 | 0.020 |
| Std Dev | 0.555 | 0.316 | 0.296 | 0.118 | 0.241 | 0.364 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | -0.106 | 0.097 | 0.000 | -0.001 | -0.006 | 0.023 |
| Std Dev | 0.555 | 0.316 | 0.296 | 0.118 | 0.241 | 0.364 |
| | *Depth to Groundwater (feet)* | | | | | *Filtered Sales (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 187.25 | 132.99 | 283.62 | 208.05 | 241.50 | 4729.98 |
| Std Dev | 48.68 | 36.95 | 84.81 | 208.05 | 86.16 | 2440.95 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | -0.002 | 0.007 | -0.008 | 0.002 | -0.005 | -0.005 |
| Std Dev | 0.048 | 0.044 | 0.015 | 0.060 | 0.038 | 0.151 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | -0.003 | 0.003 | -0.001 | 0.000 | -0.003 | -0.007 |
| Std Dev | 0.048 | 0.044 | 0.015 | 0.060 | 0.038 | 0.151 |

Notes: This table compares the counterfactual actions and states with the actual and Base scenario actions and states.

Table 29: No Property Right to Recharged Water Counterfactual: Average Annual Welfare, 2004-2013

| Player | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Appropriator Profits | | | |
| Beaumont-Cherry Valley Water District | -1.3 million | -0.1 million | 0 million |
| City of Banning | -0.2 million | 0 million | 0 million |
| South Mesa Water Company | 0 million | 0 million | 0 million |
| Yucaipa Valley Water District | -2.5 million | -0.2 million | 0 million |
| **Total appropriators** | **-3.9 million** | **-0.3 million** | **0 million** |
| | | *Average Annual Welfare (dollars)* | |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | 8 million | 0.8 million | 0 million |
| City of Banning | 7.1 million | 0.7 million | 0 million |
| South Mesa Water Company | 1.8 million | 0.2 million | 0 million |
| Yucaipa Valley Water District | 14.4 million | 1.4 million | 0 million |
| **Total appropriators** | **31.4 million** | **3 million** | **0 million** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 18.8 thousand | 1.9 thousand | -0.1 thousand |
| Riedman | 6.7 thousand | 0.8 thousand | 0 thousand |
| **Total farmers in Beaumont Basin** | **25.5 thousand** | **2.7 thousand** | **-0.1 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | 0.8 thousand | -0.3 thousand | 0 thousand |
| Illy | 4.8 thousand | 0.5 thousand | 0.2 thousand |
| Summit Cemetery District | -0.3 thousand | -1.7 thousand | -0.3 thousand |
| Hudson | 8.4 thousand | 0.9 thousand | 0 thousand |
| **Total farmers outside Beaumont Basin** | **13.7 thousand** | **-0.6 thousand** | **0 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | -20.5 thousand | 2 thousand | -1.4 thousand |
| Southern California PGA | 19.8 thousand | -7.9 thousand | -0.8 thousand |
| Oak Valley Partners | 0.2 thousand | 0.2 thousand | 0 thousand |
| Plantation on the Lake | -0.4 thousand | -0.4 thousand | 0 thousand |
| Sharondale Mesa Owners Association | -0.4 thousand | -0.2 thousand | 0 thousand |
| **Total recreational users** | **-1.4 thousand** | **-6.2 thousand** | **-2.1 thousand** |

Notes: Welfare is the present discounted value of the entire stream of per-period payoffs over the period 2004-2013. Average annual welfare is welfare divided by the number of years. Counterfactual, actual, and Base scenario welfare are calculated using the parameter estimates from the structural model. Actual welfare is calculated using actual values of actions and states in the data. Counterfactual welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 under the assumption of no property right to recharged water. Base scenario welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual welfare values, Base scenario welfare values, the difference between counterfactual and actual welfare values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario welfare values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' welfare values and 'Counterfactual Minus Base Scenario' welfare values denote the significance level of the respective differences. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table 30: No Property Right to Recharged Water Counterfactual Social Welfare, 2004-2013

| | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Producer Surplus Components | | | |
| Appropriator profits | -4.3 million | -0.3 million | 0 million |
| Farmer profits inside Beaumont Basin | 25.5 thousand | 2.7 thousand | -0.1 thousand |
| Farmer profits outside Beaumont Basin | 13.7 thousand | -0.6 thousand | 0 thousand |
| Recreational user profits | -1.4 thousand | -6.2 thousand | -2.1 thousand |
| **Total Producer Surplus** | **-4.22 million** | **-0.34 million** | **0.04 million** |
| | *Average Annual Consumer Surplus (dollars)* | | |
| Beaumont-Cherry Valley Water District | 8.7 million | 0.9 million *** | 0 million *** |
| City of Banning | 7.9 million | 0.8 million *** | 0 million *** |
| South Mesa Water Company | 2.9 million | 0.2 million *** | 0 million |
| Yucaipa Valley Water District | 13.3 million | 1.3 million *** | 0 million |
| **Total Consumer Surplus** | **32.7 million** | **3.2 million *** ** | **0 million *** ** |
| | *Average Annual Value of Property Rights (dollars)* | | |
| Beaumont-Cherry Valley Water District | -10.4 thousand | -1.6 thousand | -0.6 thousand |
| City of Banning | -2.6 thousand | -0.3 thousand | 0.1 thousand |
| South Mesa Water Company | -3.2 thousand | -0.1 thousand | 0 thousand |
| Yucaipa Valley Water District | -3.8 thousand | -0.5 thousand | -0.1 thousand |
| Farmers inside Beaumont Basin | -0.8 thousand | -0.1 thousand | 0 thousand |
| Recreational Users | -3.3 thousand | -0.4 thousand | 0 thousand |
| **Total Value of Property Rights** | **0 million** | **0 million** | **0 million** |
| | *Average Annual Value of Imported Water (dollars)* | | |
| Beaumont-Cherry Valley Water District | 847.9 thousand | 63.2 thousand | 0 million |
| City of Banning | 209.5 thousand | 21.8 thousand | 0 million |
| South Mesa Water Company | N/A | N/A | N/A |
| Yucaipa Valley Water District | 1061.8 thousand | 92.8 thousand | 0 million |
| **Total Value of Imported Water** | **2.1 million** | **177.8 thousand** | **0 million** |
| **Social Welfare** | **30.6 million** | **3 million *** ** | **0 million** |

Notes: Components of social welfare are the present discounted value of the entire stream of per-period payoffs related to each component over the period 2004-2013. Average annual values of these components are equal to the total value of the component divided by the number of years. Producer surplus is equal to the sum of profits from groundwater extraction by each group of players, and the value of holding property rights for appropriators. Consumer surplus is equal to the sum of consumer surplus for each appropriator in the sample and is determined by the residential demand model. It is not weighted by parameters in the payoff function of the appropriator. Social welfare is equal to the sum of producer surplus and consumer surplus. Counterfactual, actual, and Base scenario values are calculated using the parameter estimates from the structural model. Actual values are calculated using actual values of actions and states in the data. Counterfactual values are calculated using model predicted actions and states generated from 100 simulation runs of the open access period. Base scenario values is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual values, Base scenario values, the difference between counterfactual and actual values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' values and 'Counterfactual Minus Base Scenario' values denote the significance level of the respective differences. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table 31: No Property Right to Recharged Water Counterfactual: Simulation Statistics, 2004-2013

| | Appropriator inside Beaumont | Appropriator outside Beaumont | Farmer inside Beaumont | Farmer outside Beaumont | Golf Course / Housing Development | Appropriator Imported Water |
|---|---|---|---|---|---|---|
| | | | *Groundwater Extraction (acre-feet)* | | | *Artificial Recharge (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 2932.01 | 4743.21 | 274.91 | 218.15 | 517.95 | 3580.58 |
| Std Dev | 2891.18 | 2602.06 | 380.28 | 218.15 | 433.06 | 2311.70 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | -0.117 | 0.072 | 0.123 | -0.001 | -0.003 | -0.014 |
| Std Dev | 0.418 | 0.271 | 0.306 | 0.121 | 0.245 | 0.329 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | -0.135 | 0.077 | -0.005 | -0.003 | -0.002 | -0.011 |
| Std Dev | 0.418 | 0.271 | 0.306 | 0.121 | 0.245 | 0.329 |
| | | | *Depth to Groundwater (feet)* | | | *Filtered Sales (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 187.91 | 133.05 | 283.98 | 207.55 | 241.82 | 4756.54 |
| Std Dev | 48.59 | 37.11 | 84.88 | 207.55 | 86.90 | 2448.01 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | 0.002 | 0.008 | -0.007 | 0.000 | -0.004 | 0.000 |
| Std Dev | 0.047 | 0.046 | 0.015 | 0.060 | 0.036 | 0.147 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | 0.001 | 0.003 | 0.001 | -0.002 | -0.002 | -0.001 |
| Std Dev | 0.047 | 0.046 | 0.015 | 0.060 | 0.036 | 0.147 |

Notes: This table compares the counterfactual actions and states with the actual and Base scenario actions and states.

Table 32: Revised Safe Yield Counterfactual: Average Annual Welfare, 2004-2013

| Player | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Appropriator Profits | | | |
| Beaumont-Cherry Valley Water District | -1.3 million | -0.1 million | 0 million |
| City of Banning | -0.2 million | 0 million | 0 million |
| South Mesa Water Company | 0 million | 0 million | 0 million |
| Yucaipa Valley Water District | -2.5 million | -0.2 million | 0 million |
| **Total appropriators** | **-3.9 million** | **-0.3 million** | **0.1 million** |
| | | *Average Annual Welfare (dollars)* | |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | 8 million | 0.8 million | 0 million |
| City of Banning | 7.1 million | 0.7 million | 0 million |
| South Mesa Water Company | 1.9 million | 0.2 million | 0 million |
| Yucaipa Valley Water District | 14.4 million | 1.4 million | 0 million |
| **Total appropriators** | **31.4 million** | **3.1 million** | **0 million** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 13.6 thousand | -3.4 thousand | -5.3 thousand |
| Riedman | 6.3 thousand | 0.4 thousand | -0.4 thousand |
| **Total farmers in Beaumont Basin** | **19.8 thousand** | **-3 thousand** | **-5.8 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | 0.7 thousand | -0.3 thousand | 0 thousand |
| Illy | 4.7 thousand | 0.4 thousand | 0.1 thousand |
| Summit Cemetery District | 0.1 thousand | -1.3 thousand | 0.2 thousand |
| Hudson | 8.4 thousand | 0.9 thousand | 0 thousand |
| **Total farmers outside Beaumont Basin** | **14 thousand** | **-0.3 thousand** | **0.3 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | -17.8 thousand | 4.7 thousand | 1.3 thousand |
| Southern California PGA | 20.5 thousand | -7.1 thousand | 0 thousand |
| Oak Valley Partners | 0.1 thousand | 0.2 thousand | 0 thousand |
| Plantation on the Lake | -0.4 thousand | -0.4 thousand | 0 thousand |
| Sharondale Mesa Owners Association | -0.7 thousand | -0.5 thousand | -0.3 thousand |
| **Total recreational users** | **1.7 thousand** | **-3.1 thousand** | **0.9 thousand** |

Notes: Welfare is the present discounted value of the entire stream of per-period payoffs over the period 2004-2013. Average annual welfare is welfare divided by the number of years. Counterfactual, actual, and Base scenario welfare are calculated using the parameter estimates from the structural model. Actual welfare is calculated using actual values of actions and states in the data. Counterfactual welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 under the assumption of revised safe yield. Base scenario welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual welfare values, Base scenario welfare values, the difference between counterfactual and actual welfare values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario welfare values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' welfare values and 'Counterfactual Minus Base Scenario' welfare values denote the significance level of the respective differences. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table 33: Revised Safe Yield Counterfactual Social Welfare, 2004-2013

| | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Producer Surplus Components | | | |
| Appropriator profits | -4.2 million | -0.3 million | 0.1 million |
| Farmer profits inside Beaumont Basin | 19.8 thousand | -3 thousand | -5.8 thousand |
| Farmer profits outside Beaumont Basin | 14 thousand | -0.3 thousand | 0.3 thousand |
| Recreational user profits | 1.7 thousand | -3.1 thousand | 0.9 thousand |
| **Total Producer Surplus** | **-4.19 million** | **-0.31 million** | **0.07 million** |
| | *Average Annual Consumer Surplus (dollars)* | | |
| Beaumont-Cherry Valley Water District | 8.7 million | 0.9 million *** | 0 million ** |
| City of Banning | 7.9 million | 0.8 million *** | 0 million *** |
| South Mesa Water Company | 2.8 million | 0.2 million *** | 0 million |
| Yucaipa Valley Water District | 13.2 million | 1.3 million *** | 0 million *** |
| **Total Consumer Surplus** | **32.7 million** | **3.2 million *** ** | **0 million *** ** |
| | *Average Annual Value of Property Rights (dollars)* | | |
| Beaumont-Cherry Valley Water District | -9.8 thousand | -1.1 thousand | 0 thousand |
| City of Banning | -2.6 thousand | -0.3 thousand | 0.1 thousand |
| South Mesa Water Company | -3.3 thousand | -0.2 thousand | -0.1 thousand |
| Yucaipa Valley Water District | -3.7 thousand | -0.4 thousand | 0 thousand |
| Farmers inside Beaumont Basin | -0.4 thousand | 0.2 thousand | 0.4 thousand |
| Recreational Users | -3.8 thousand | -0.9 thousand | -0.5 thousand |
| **Total Value of Property Rights** | **0 million** | **0 million** | **0 million** |
| | *Average Annual Value of Imported Water (dollars)* | | |
| Beaumont-Cherry Valley Water District | 853.4 thousand | 68.7 thousand | 0 million |
| City of Banning | 207.4 thousand | 19.7 thousand | 0 million |
| South Mesa Water Company | N/A | N/A | N/A |
| Yucaipa Valley Water District | 1063.7 thousand | 94.6 thousand | 0 million |
| **Total Value of Imported Water** | **2.1 million** | **183 thousand** | **0 million** |
| **Social Welfare** | **30.6 million** | **3 million *** ** | **0 million** |

Notes: Components of social welfare are the present discounted value of the entire stream of per-period payoffs related to each component over the period 2004-2013. Average annual values of these components are equal to the total value of the component divided by the number of years. Producer surplus is equal to the sum of profits from groundwater extraction by each group of players, and the value of holding property rights for appropriators. Consumer surplus is equal to the sum of consumer surplus for each appropriator in the sample and is determined by the residential demand model. It is not weighted by parameters in the payoff function of the appropriator. Social welfare is equal to the sum of producer surplus and consumer surplus. Counterfactual, actual, and Base scenario values are calculated using the parameter estimates from the structural model. Actual values are calculated using actual values of actions and states in the data. Counterfactual values are calculated using model predicted actions and states generated from 100 simulation runs of the open access period. Base scenario values is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual values, Base scenario values, the difference between counterfactual and actual values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' values and 'Counterfactual Minus Base Scenario' values denote the significance level of the respective differences. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table 34: Revised Safe Yield Counterfactual: Simulation Statistics, 2004-2013

| | Appropriator inside Beaumont | Appropriator outside Beaumont | Farmer inside Beaumont | Farmer outside Beaumont | Golf Course / Housing Development | Appropriator Imported Water |
|---|---|---|---|---|---|---|
| | | | *Groundwater Extraction (acre-feet)* | | | *Artificial Recharge (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 3248.53 | 4472.62 | 110.68 | 217.96 | 455.66 | 3594.49 |
| Std Dev | 3389.89 | 2681.56 | 192.48 | 217.96 | 388.73 | 2354.89 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | -0.021 | 0.010 | -0.547 | -0.002 | -0.123 | -0.010 |
| Std Dev | 0.211 | 0.159 | 0.804 | 0.119 | 0.256 | 0.310 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | -0.040 | 0.016 | -0.675 | -0.004 | -0.122 | -0.007 |
| Std Dev | 0.211 | 0.159 | 0.804 | 0.119 | 0.256 | 0.310 |
| | | | *Depth to Groundwater (feet)* | | | *Filtered Sales (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 187.03 | 132.69 | 277.30 | 207.04 | 243.42 | 4764.59 |
| Std Dev | 47.89 | 37.14 | 86.31 | 207.04 | 87.11 | 2424.98 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | -0.003 | 0.005 | -0.030 | -0.003 | 0.002 | 0.002 |
| Std Dev | 0.048 | 0.046 | 0.019 | 0.060 | 0.036 | 0.145 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | -0.004 | 0.001 | -0.023 | -0.005 | 0.005 | 0.000 |
| Std Dev | 0.048 | 0.046 | 0.019 | 0.060 | 0.036 | 0.145 |

Notes: This table compares the counterfactual actions and states with the actual and Base scenario actions and states.

# Appendix

# A Supplementary Tables and Figures

Table A.1: Summary statistics for groundwater variables for appropriators, 1991-1996

| | Mean | Min | Max | Std. | Obs |
|---|---|---|---|---|---|
| **Appropriators** | | | | | |
| Extraction inside management zone, acre-feet | 3319.9 | 494 | 11096 | 3667.65 | 40 |
| Extraction outside management zone, acre-feet | 4426.40 | 1206 | 9449 | 2811.6 | 40 |
| Recharged SWP water, acre-feet | 2542.36 | 0 | 7979 | 2748.52 | 20 |
| SWP water sold to customers YVWD, acre-feet | 4754.3 | 1257 | 7706 | 2342.6 | 10 |
| Water rights purchased (sold), acre-feet | 0 | -3500 | 3500 | 1224.74 | 40 |
| Retail price, untreated water, dollars/acre-foot | 424.78 | 326.00 | 590.25 | 105.45 | 10 |
| Depth to groundwater, feet | 142.6 | 102.99 | 197.85 | 32.17 | 40 |
| Depth to groundwater inside management zone, feet | 187.54 | 102.99 | 274.22 | 48.98 | 40 |
| Depth to groundwater outside management zone, feet | 132.05 | 98.19 | 201.33 | 37.17 | 40 |
| Total wells owned by i before t | 27.93 | 5 | 52 | 17.28 | 40 |
| Total wells owned by i before t, inside Beaumont Basin | 6.45 | 2 | 14 | 4.7 | 40 |
| Total wells owned by i before t, outside Beaumont Basin | 21.48 | 3 | 49 | 17.14 | 40 |
| Distance to artificial recharge facility at wells inside Beaumont Basin (feet) | 6144.69 | 2629.76 | 8546.08 | 2202.04 | 40 |
| Distance to artificial recharge facility at wells outside Beaumont Basin (feet) | 7887.61 | 5613.37 | 8800.08 | 1334.42 | 40 |
| Average depth of wells, feet | 700.570 | 623.14 | 743.71 | 49.96 | 40 |
| Population of city in service area | 29588.53 | 9894.98 | 49749.13 | 13934.04 | 40 |
| Average household size | 2.81 | 2.55 | 3.13 | .17 | 40 |
| Annual starting allocation property rights, acre-feet | 12336.43 | 2097.1 | 46009.2 | 11312.5 | 40 |
| Annual allocation property rights net of trades, acre-feet | 12336.43 | 2097.1 | 46009.2 | 11550.78 | 40 |
| Annual allocation property rights net of trades and recharge, acre-feet | 13607.61 | 2097.1 | 47209.2 | 12855.85 | 40 |
| Beaumont Basin extraction limit for year t, acre-feet | 29313.14 | 2097.1 | 167813.41 | 37775.28 | 40 |
| Beaumont Basin extraction limit, after trades, for year t, acre-feet | 29313.14 | 2097.1 | 167813.41 | 37782.41 | 40 |
| Beaumont Basin extraction limit after trades and recharge for year t, acre-feet | 30584.32 | 2097.1 | 169013.41 | 38339.79 | 40 |
| Remaining surplus water rights to be allocated in future years, acre-feet | 16200 | 0 | 57817 | 15145.75 | 40 |

Sources: AWWA CA/Nevada Survey 2007-2015; CA Franchise Tax Board; USGS; CA-SWP; CA Dept. Finance; PRISM; FRED; BEA; USDA; SGPWA; STWMA; Beaumont Watermaster; Groundwater Recordation Program.

Table A.2: Summary statistics for groundwater variables for overlying users, 1991-1996

| | Mean | Min | Max | Std. | Obs |
|---|---|---|---|---|---|
| **Farmers** | | | | | |
| Extraction inside management zone, acre-feet | 257.42 | 5 | 1477 | 402.06 | 19 |
| Extraction outside management zone, acre-feet | 218.38 | 65 | 521 | 154.52 | 40 |
| Depth to groundwater, feet | 231.41 | 106.5 | 380 | 72.5100 | 59 |
| Depth to groundwater inside management zone, feet | 281.57 | 192.91 | 380 | 89.1000 | 19 |
| Depth to groundwater outside management zone, feet | 207.59 | 106.5 | 275.92 | 48.46 | 40 |
| Total wells owned by i before t | 2.54 | 1 | 4 | 1.04 | 59 |
| Total wells owned by i before t, inside Beaumont Basin | .78 | 0 | 4 | 1.43 | 59 |
| Total wells owned by i before t, outside Beaumont Basin | 1.76 | 0 | 3 | 1.36 | 59 |
| Distance to artificial recharge facility at wells inside Beaumont Basin (feet) | 4588.76 | 3826.48 | 5274.81 | 742.97 | 19 |
| Distance to artificial recharge facility at wells outside Beaumont Basin (feet) | 5855.87 | 2229.3 | 8812.38 | 2593.25 | 40 |
| Average depth of wells, feet | 581.560 | 171 | 1043.25 | 346.4 | 38 |
| Beaumont Basin extraction limit for year t, acre-feet | 2943.63 | 80 | 7044.5 | 2369.35 | 19 |
| Annual starting allocation property rights, acre-feet | 1025.74 | 550 | 1784 | 527.85 | 19 |
| Annual allocation property rights net of trades, acre-feet | 1007.61 | 550 | 1784 | 505.82 | 19 |
| **Recreational Users** | | | | | |
| Total extraction, acre-feet | 590.17 | 131 | 1753 | 422.85 | 44 |
| Depth to groundwater, feet | 242.83 | 153.09 | 412.1 | 90.17 | 44 |
| Total wells owned by i before t | 2 | 1 | 4 | 1.18 | 44 |
| Distance to artificial recharge facility at wells inside Beaumont Basin (feet) | 4585.56 | 2282.69 | 6243.29 | 1402.68 | 44 |
| Average depth of wells, feet | 1134.58 | 907.5 | 1370 | 205.31 | 24 |
| Beaumont Basin extraction limit for year t, acre-feet | 2108.39 | 59 | 7122 | 2042.14 | 44 |
| Annual starting allocation property rights, acre-feet | 1057.59 | 200 | 2200 | 763 | 44 |

Sources: AWWA CA/Nevada Survey 2007-2015; CA Franchise Tax Board; USGS; CA-SWP; CA Dept. Finance; PRISM; FRED; BEA; USDA; SGPWA; STWMA; Beaumont Watermaster; Groundwater Recordation Program.

Table A.3: Summary statistics for additional state variables, 1991-1996

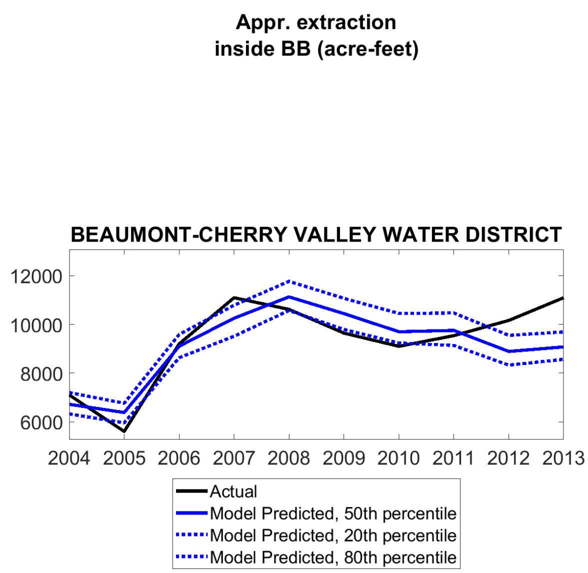
| | Mean | Min | Max | Std. | Obs |
|---|---|---|---|---|---|
| **Annual State Variables** | | | | | |
| March price, alfalfa, dollars/ton | 134.93 | 85.90 | 219.00 | 43.98 | 10.00 |
| March price, raisin-grapes, dollars/ton | 119.50 | 110.00 | 133.00 | 6.40 | 10.00 |
| March price, strawberries, dollars/lb | 1.03 | 0.71 | 1.34 | 0.20 | 10.00 |
| March price, sweet cherries, dollars/ton | 199.70 | 184.00 | 210.00 | 8.99 | 10.00 |
| March price, canning-olives, dollars/ton | 91.50 | 87.40 | 95.70 | 3.41 | 10.00 |
| Average crop price, (dollars per unit) | 109.33 | 97.44 | 129.20 | 9.95 | 10.00 |
| Electricity price, agricultural, dollars/kwh | 0.14 | 0.12 | 0.17 | 0.02 | 10.00 |
| CA real GDP per capita, 1997 chained dollars | 56205.70 | 53474.00 | 58030.00 | 1549.21 | 10.00 |
| Retail price, untreated water, dollars/acre-foot | 424.78 | 326.00 | 590.25 | 105.45 | 10.00 |
| Share of Table A SWP water available for purchase | 0.62 | 0.35 | 1.00 | 0.23 | 10.00 |
| Riverside County housing starts | 11352.60 | 2316.00 | 30898.00 | 11479.42 | 10.00 |
| Total Table A allocation of SWP water for region (acre-feet) | 13195.00 | 6000.00 | 17300.00 | 5340.96 | 10.00 |
| **Other Player State Variables** | | | | | |
| Saturated hydraulic conductivity, ft/day | 30.75 | 5.85 | 92.00 | 30.14 | 143.00 |
| Saturated hydraulic conductivity in management zone, ft/day | 30.17 | 5.85 | 92.00 | 27.50 | 103.00 |
| Saturated hydraulic conductivity out management zone, ft/day | 33.12 | 5.85 | 105.36 | 33.61 | 80.00 |
| Extraction at wells owned by others, 1 to 2 miles | 651.10 | 0.00 | 4794.00 | 1031.63 | 143.00 |
| Extraction at wells owned by others, 3 to 4 miles | 6477.84 | 0.00 | 22994.95 | 7312.09 | 143.00 |
| Extraction at wells inside managment zone owned by others, 0.5 to 1 miles | 345.75 | 0.00 | 2824.00 | 618.65 | 143.00 |
| Extraction at wells inside managment zone owned by others, 1 to 2 miles | 1427.71 | 0.00 | 13057.00 | 2814.81 | 143.00 |
| Precipitation, (Jan-March) (inches) | 7.62 | 2.06 | 25.31 | 4.70 | 143.00 |
| Inches precipitation, (Apr-Oct) | 3.12 | 0.45 | 12.04 | 2.23 | 143.00 |
| Inches precipitation, full year | 14.97 | 7.10 | 43.20 | 7.24 | 143.00 |
| Degree-days (>90 F), (Apr-Oct) | 87.63 | 25.00 | 126.00 | 22.15 | 143.00 |
| Evapotranspiration, inches, full year | 4.85 | 4.43 | 5.20 | 0.22 | 143.00 |

Sources: AWWA CA/Nevada Survey 2007-2015; CA Franchise Tax Board; USGS; CA-SWP; CA Dept. Finance; PRISM; FRED; BEA; USDA; SGPWA; STWMA; Beaumont Watermaster; Groundwater Recordation Program.

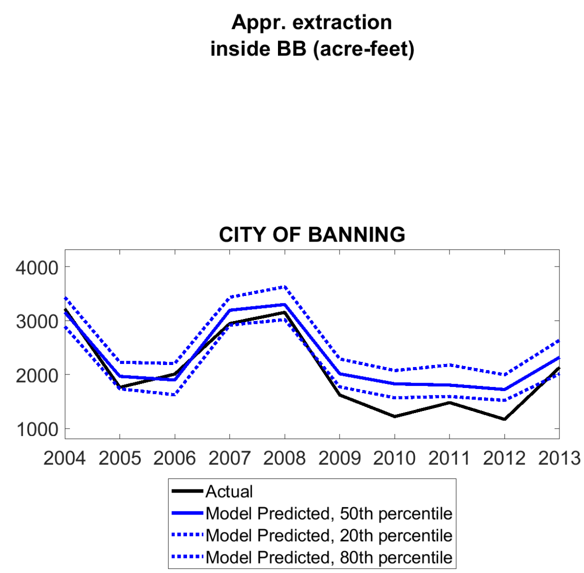
Table A.4: Summary statistics for demand estimation

| | Mean | Min | Max | Std. | Obs |
|---|---|---|---|---|---|
| **Demand estimation sample** | | | | | |
| Household monthly consumption (hundred cubic feet) | 17.38 | 1.00 | 38.00 | 6.66 | 210 |
| Average water price (dollars per hundred cubic feet) | 1.71 | 0.25 | 19.77 | 2.36 | 210 |
| SWP Equivalent Unit Charge (dollars per acre-foot) | 334.26 | 31.46 | 2,164.80 | 296.16 | 210 |
| Electricity price (dollars per kwh) x Depth to groundwater (feet) | 5.21 | 0.05 | 30.83 | 5.28 | 210 |
| Household size | 2.84 | 1.94 | 4.53 | 0.47 | 210 |
| Median Adjusted Gross Income (dollars) | 15,986.30 | 11,135.96 | 25,277.77 | 2,749.63 | 210 |
| Unemployment rate (percent) | 8.43 | 5.38 | 11.71 | 2.67 | 210 |
| Precipitation, full year (inches) | 12.78 | 1.60 | 56.16 | 9.57 | 210 |

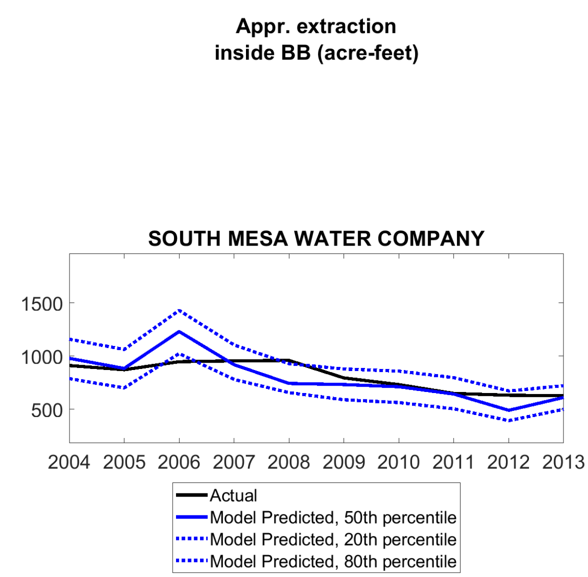
Sources: AWWA CA/Nevada Survey 2007-2015; CA Franchise Tax Board; USGS; CA-SWP; CA Dept. Finance; PRISM; FRED; BEA; USDA; SGPWA; STWMA; Beaumont Watermaster; Groundwater Recordation Program.



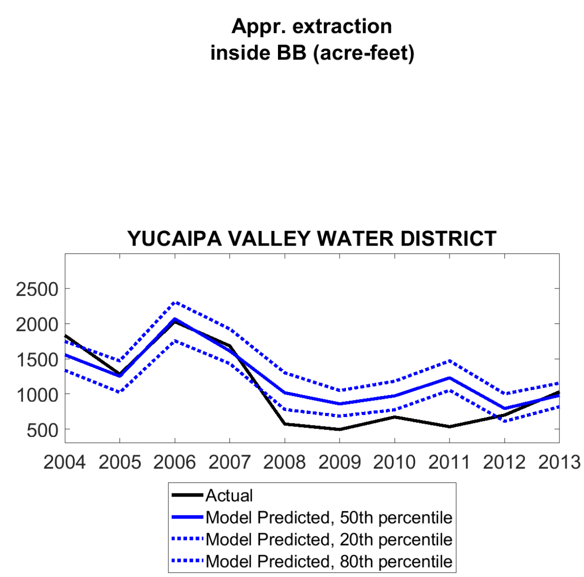

(a) Beaumont-Cherry Valley Water District




(b) City of Banning

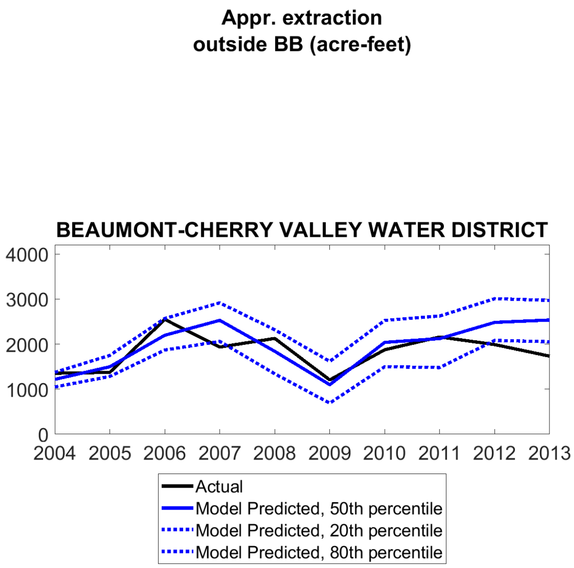



(c) South Mesa Water Company

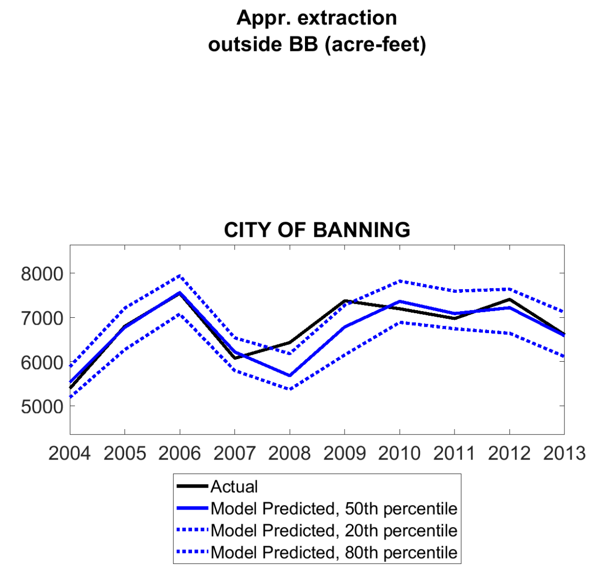



(d) Yucaipa Valley Water District

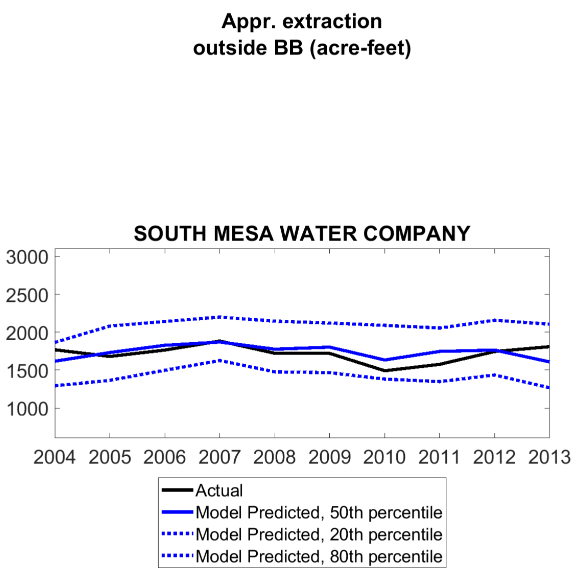
Figure A.1: Model Fit Comparison: Appropriator Extraction in Beaumont Basin



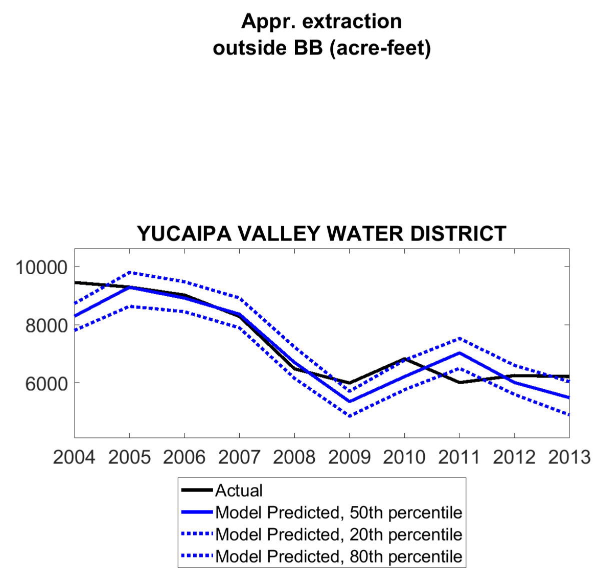

(a) Beaumont-Cherry Valley Water District




(b) City of Banning

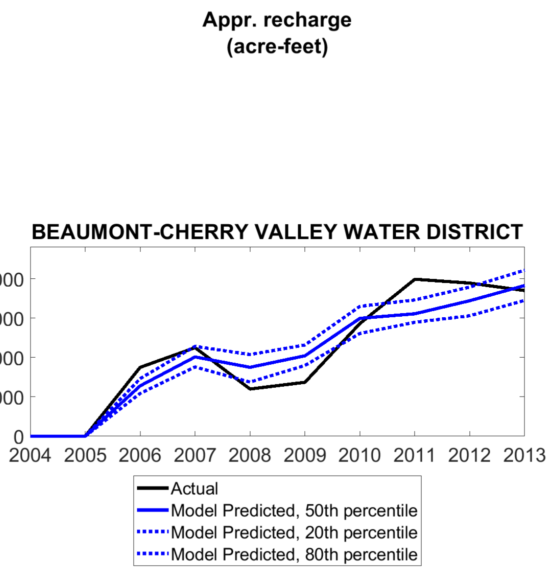



(c) South Mesa Water Company

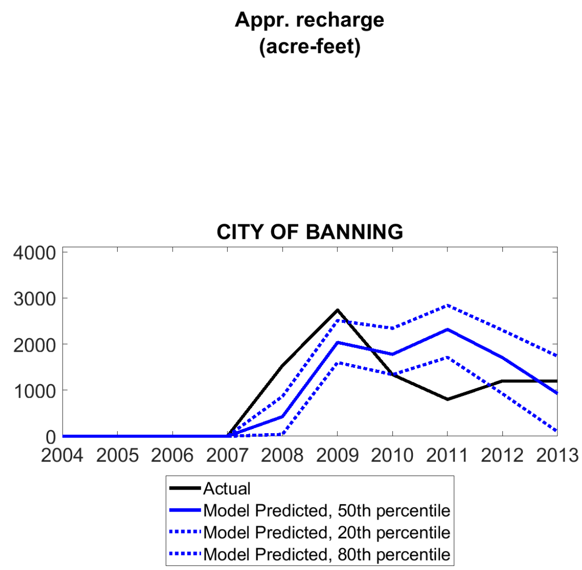



(d) Yucaipa Valley Water District

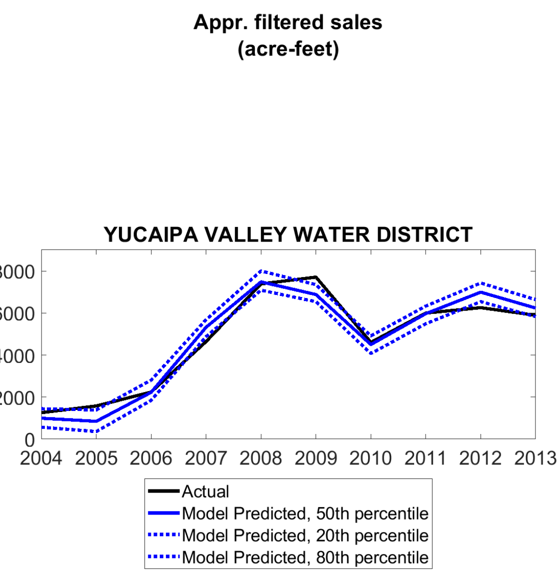
Figure A.2: Model Fit Comparison: Appropriator Extraction outside Beaumont Basin




(a) Beaumont-Cherry Valley Water District

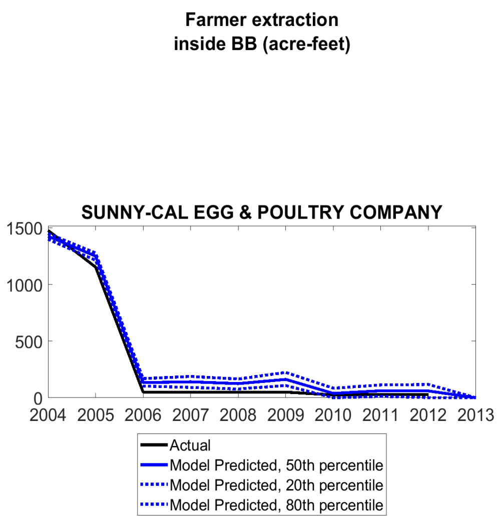



(b) City of Banning

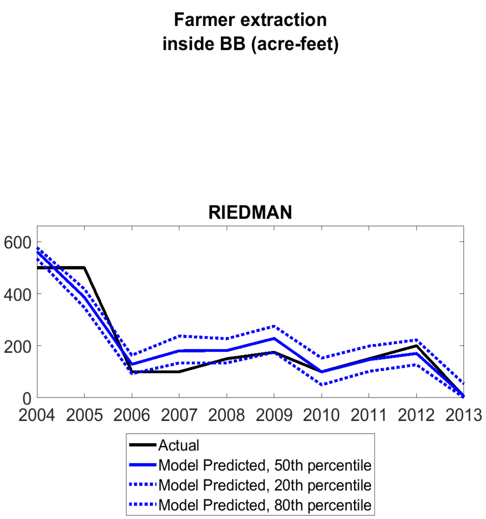



(c) Yucaipa Valley Water District

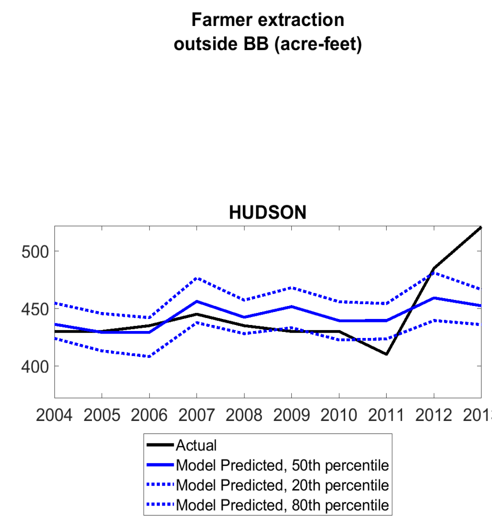
Figure A.3: Model Fit Comparison: Appropriator Water Imports



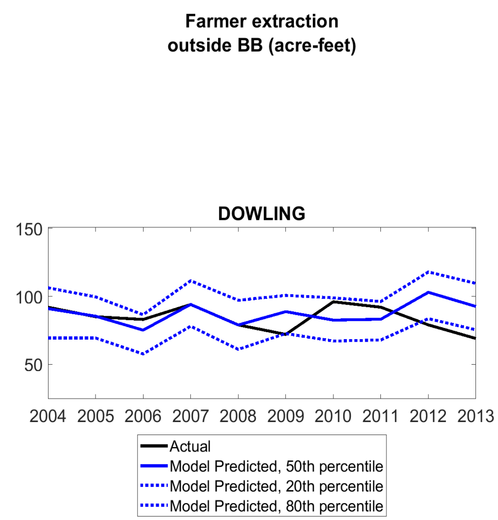

(a) Sunny-Cal Egg Co.



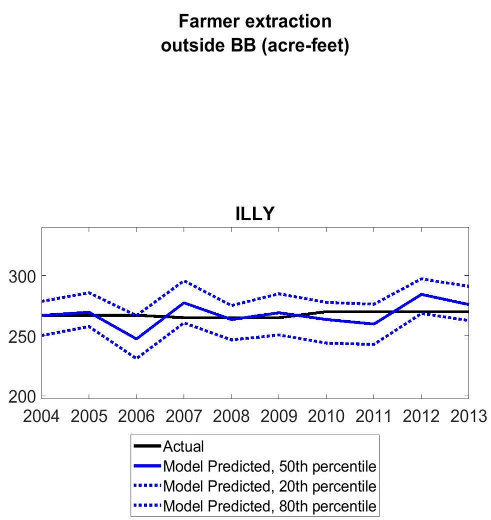

(b) Riedman



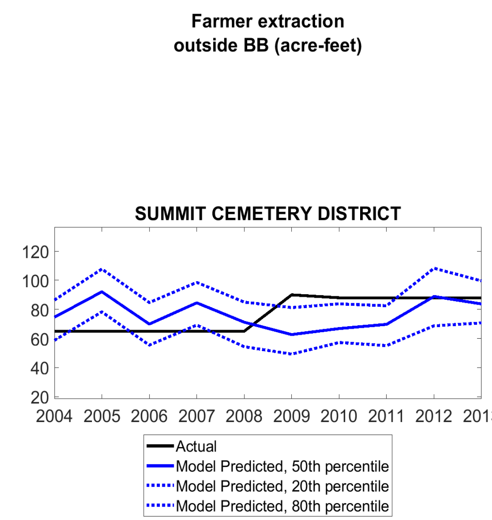

(c) Hudson




(d) Dowling

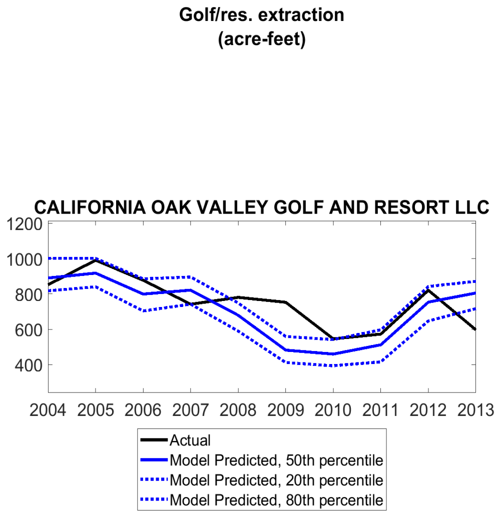



(e) Illy

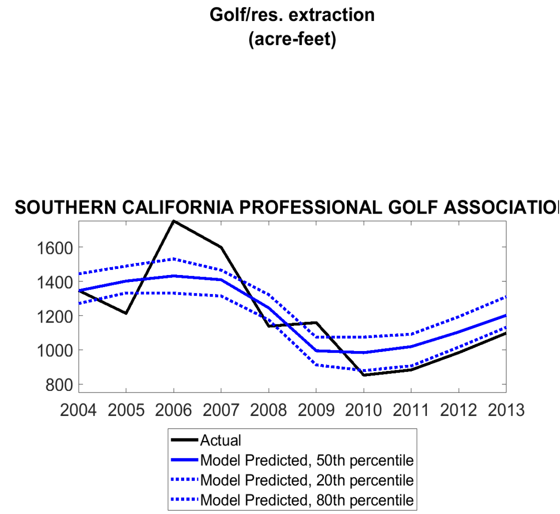



(f) Summit Cemetery District

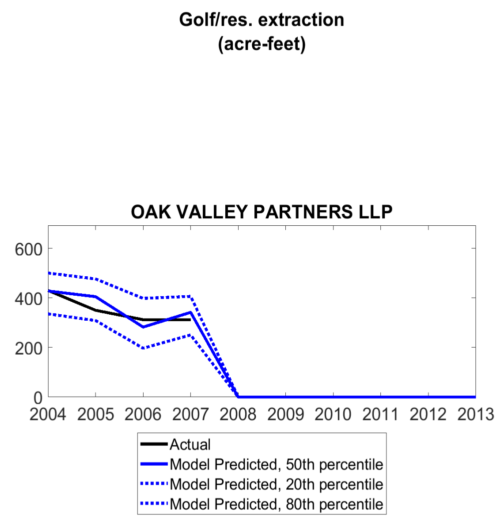
Figure A.4: Model Fit Comparison: Farmer Extraction



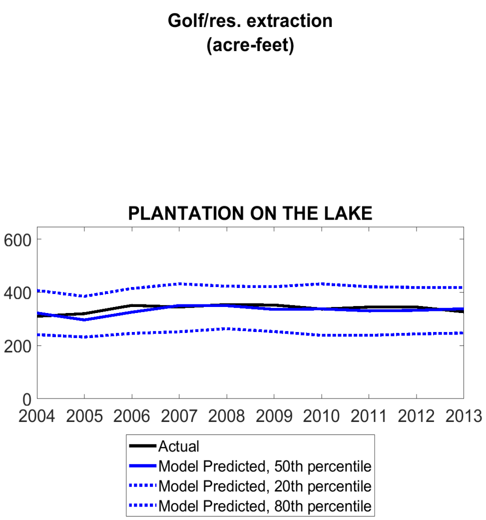

(a) California Oak Valley Golf and Resort LLC



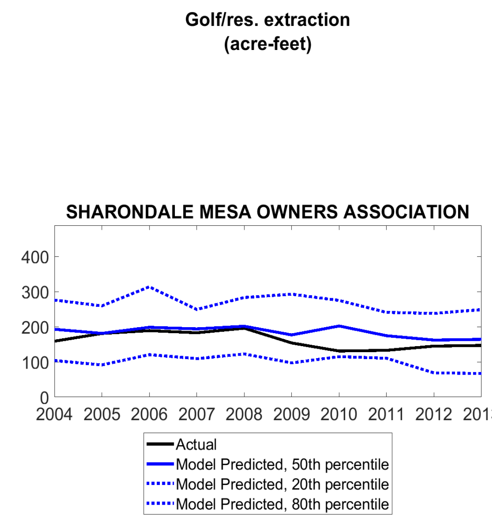

(b) Southern California PGA




(c) Oak Valley Partners LLP

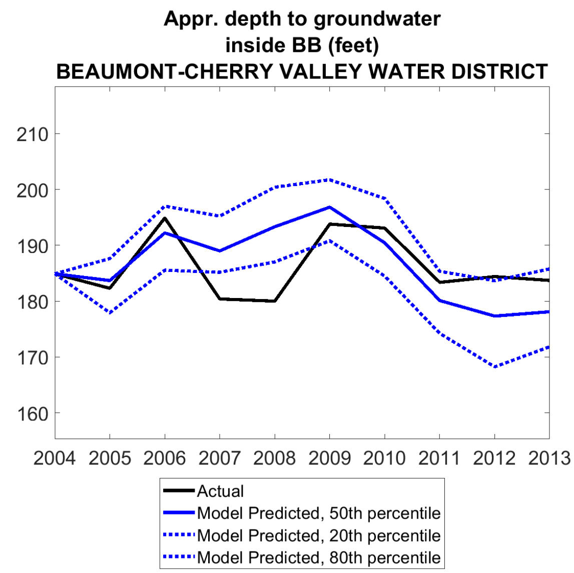



(d) Plantation on the Lake

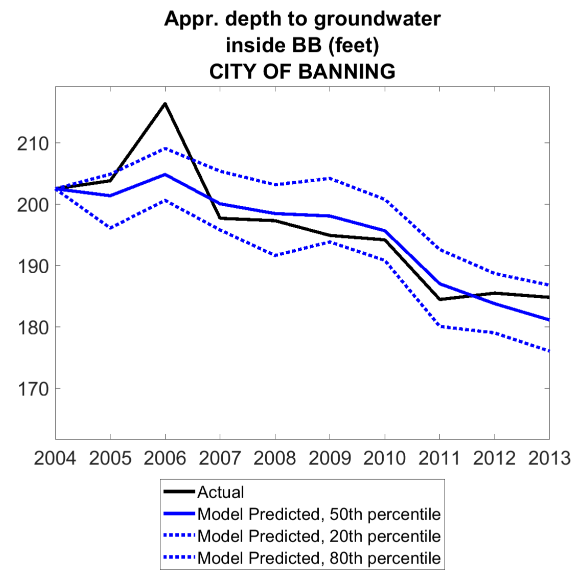



(e) Sharondale Mesa Owners Association

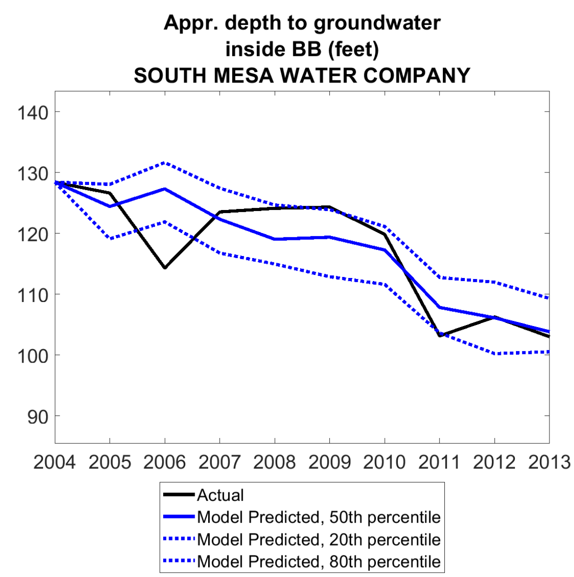
Figure A.5: Model Fit Comparison: Recreational User Extraction



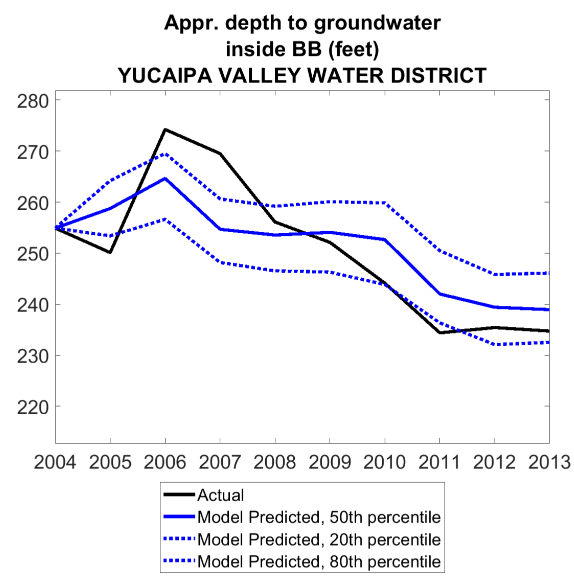

(a) Beaumont-Cherry Valley Water District




(b) City of Banning

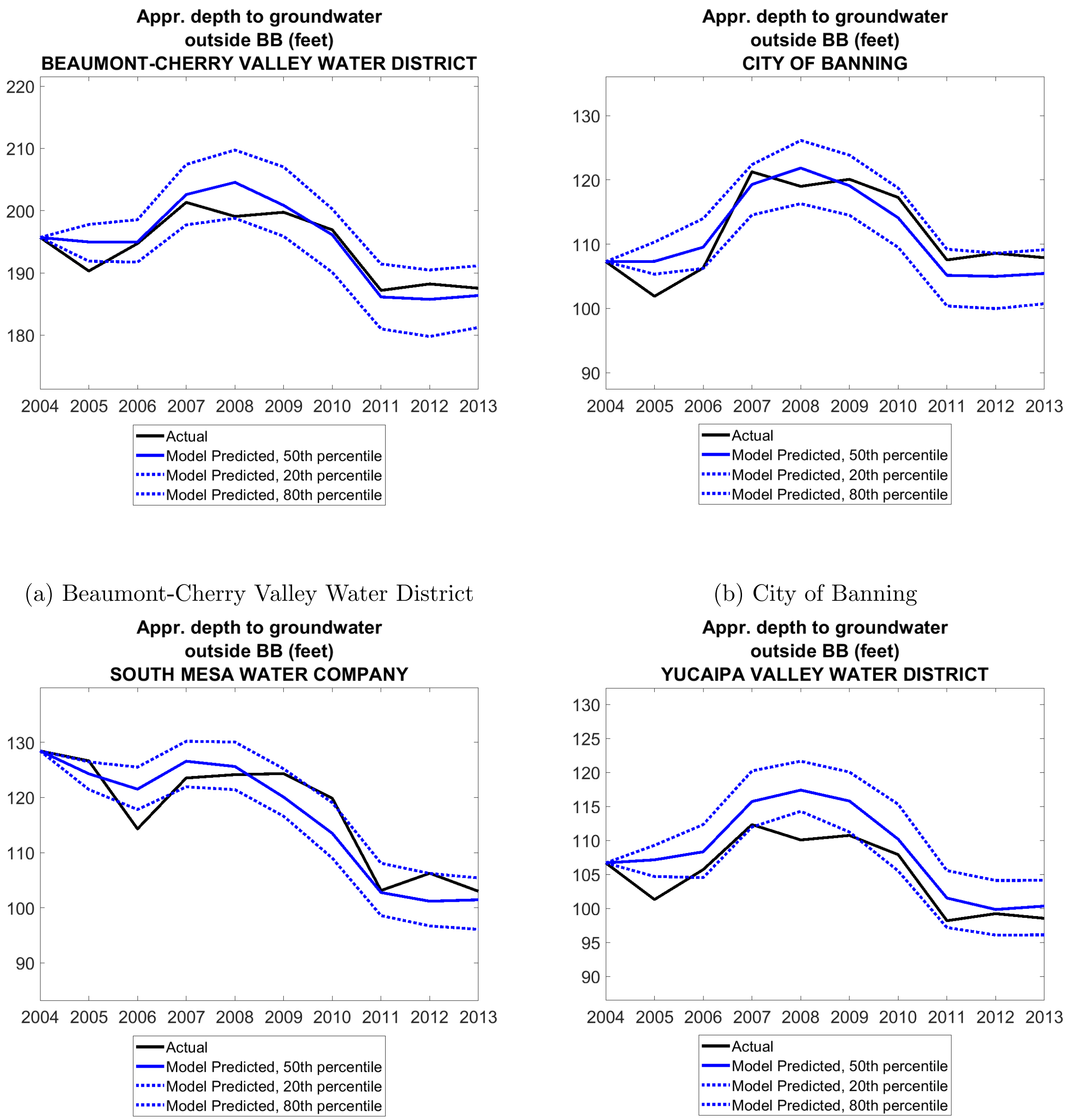



(c) South Mesa Water Company




(d) Yucaipa Valley Water District

Figure A.6: Model Fit Comparison: Appropriator Depth to Groundwater in Beaumont Basin



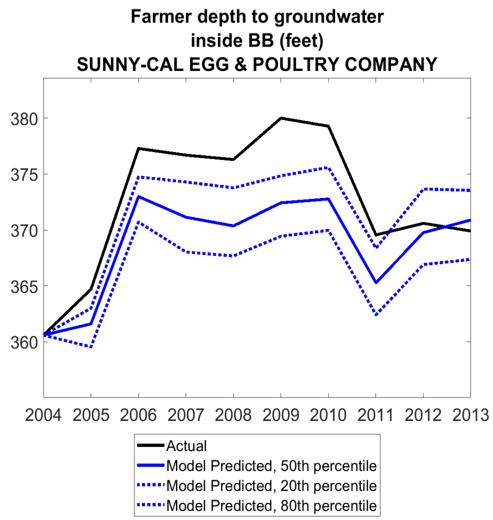

(a) Beaumont-Cherry Valley Water District

(b) City of Banning

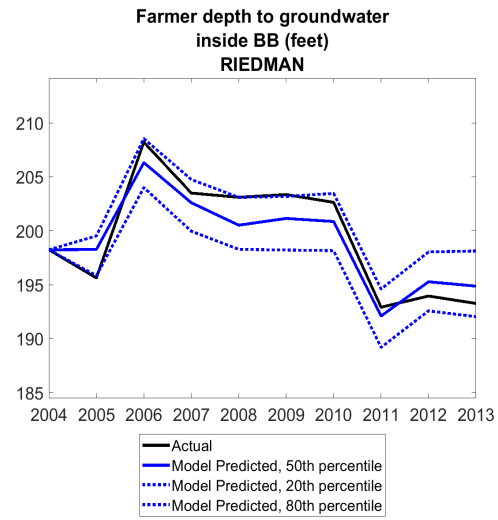
(c) South Mesa Water Company

(d) Yucaipa Valley Water District

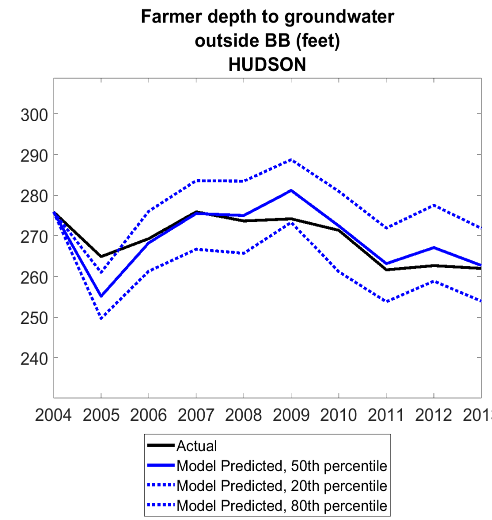
Figure A.7: Model Fit Comparison: Appropriator Depth to Groundwater outside Beaumont Basin



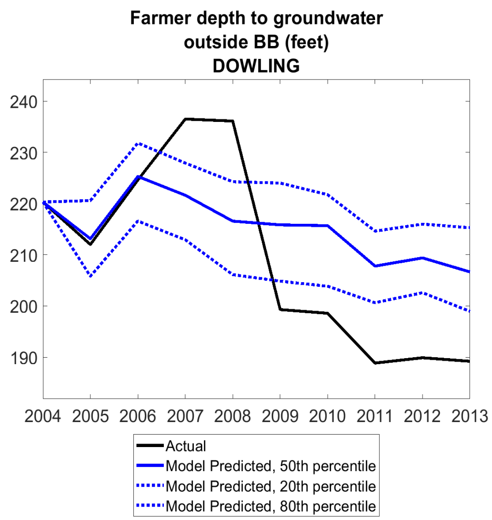

(a) Sunny-Cal Egg Co.



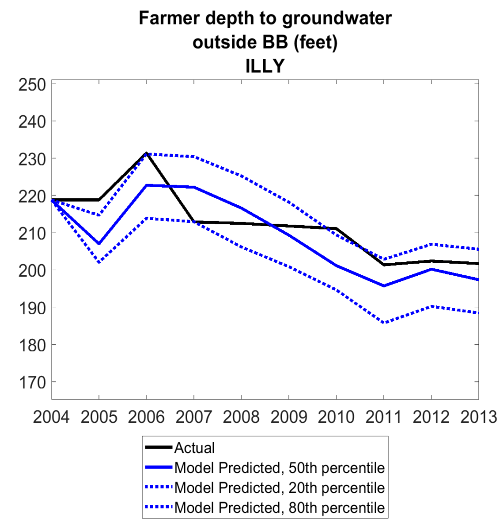

(b) Riedman



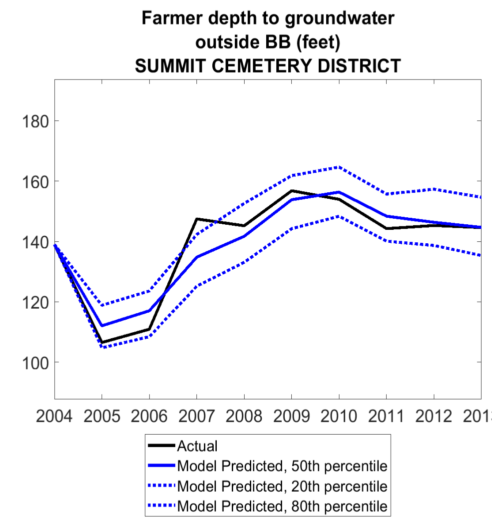

(c) Hudson




(d) Dowling

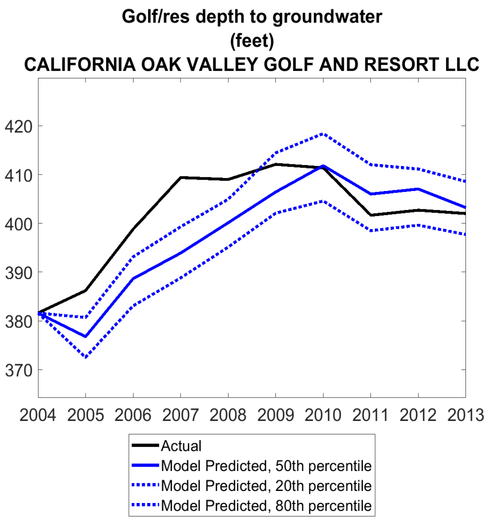



(e) Illy

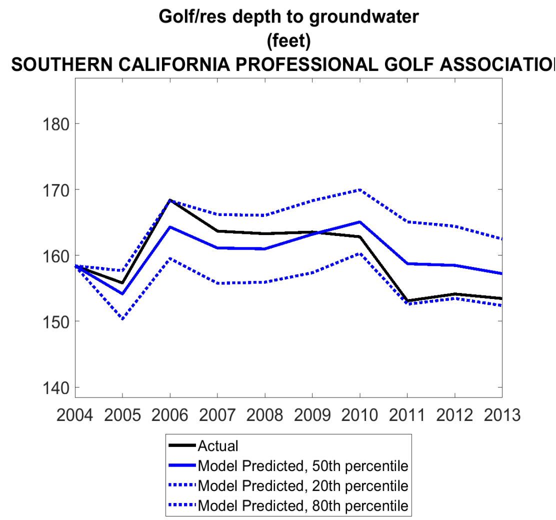



(f) Summit Cemetery District

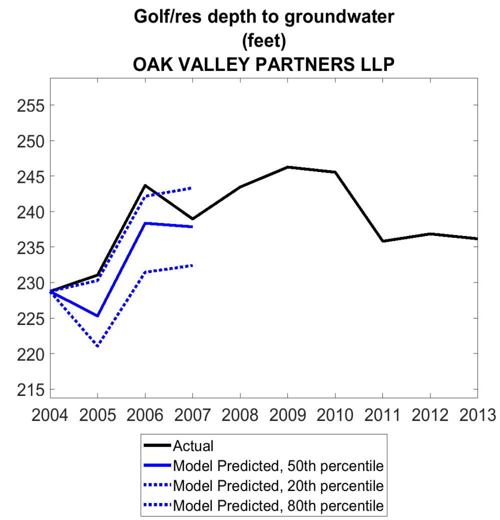
Figure A.8: Model Fit Comparison: Farmer Depth to Groundwater



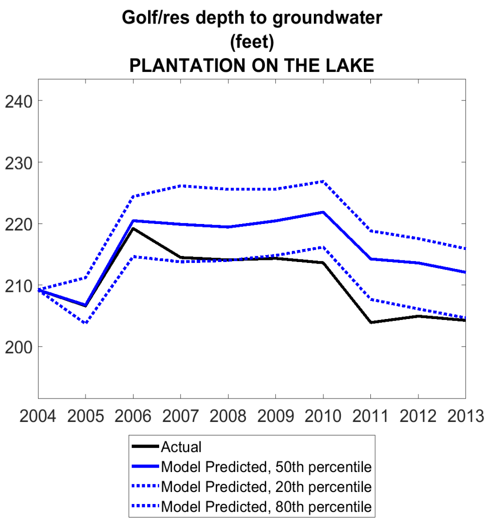

(a) California Oak Valley Golf and Resort LLC



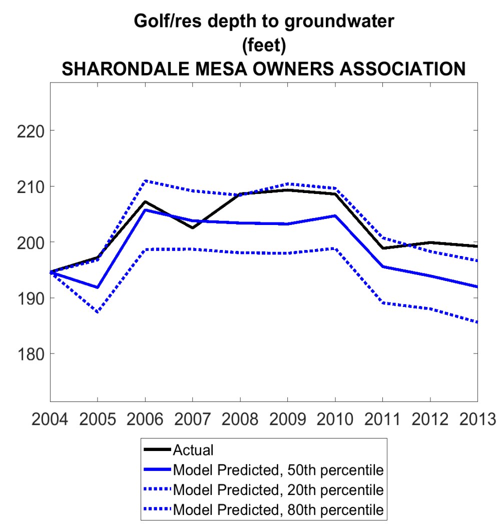

(b) Southern California PGA




(c) Oak Valley Partners LLP




(d) Plantation on the Lake




(e) Sharondale Mesa Owners Association

Figure A.9: Model Fit Comparison: Recreational User Depth to Groundwater

Table A.5: Model Predicted vs. Actual Average Annual Welfare, 2004-2013

| | *Average Annual Welfare (dollars)* | | |
|---|---|---|---|
| Player | Actual | Model Predicted | Model Predicted Minus Actual |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | 7.2 million | 8 million | 0.8 million |
| City of Banning | 6.4 million | 7.1 million | 0.7 million *** |
| South Mesa Water Company | 1.7 million | 1.8 million | 0.2 million *** |
| Yucaipa Valley Water District | 13 million | 14.4 million | 1.4 million *** |
| **Total appropriators** | **28.3 million** | **31.4 million** | **3.1 million *** ** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 16.9 thousand | 18.9 thousand | 2 thousand |
| Riedman | 5.9 thousand | 6.7 thousand | 0.8 thousand |
| **Total farmers in Beaumont Basin** | **22.8 thousand** | **25.6 thousand** | **2.8 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | 1 thousand | 0.8 thousand | -0.3 thousand |
| Illy | 4.3 thousand | 4.6 thousand | 0.3 thousand |
| Summit Cemetery District | 1.4 thousand | 0 thousand | -1.5 thousand |
| Hudson | 7.6 thousand | 8.4 thousand | 0.8 thousand |
| **Total farmers outside Beaumont Basin** | **14.3 thousand** | **13.7 thousand** | **-0.6 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | -22.5 thousand | -19.1 thousand | 3.4 thousand |
| Southern California PGA | 27.6 thousand | 20.5 thousand | -7.1 thousand |
| Oak Valley Partners | -0.1 thousand | 0.1 thousand | 0.2 thousand |
| Plantation on the Lake | 0 thousand | -0.4 thousand | -0.4 thousand |
| Sharondale Mesa Owners Association | -0.2 thousand | -0.4 thousand | -0.2 thousand |
| **Total recreational users** | **4.8 thousand** | **0.8 thousand** | **-4 thousand** |

Notes: Welfare is the present discounted value of the entire stream of per-period payoffs over the period 2004-2013. Average annual welfare is welfare divided by the number of years. 'Difference from actual' is the difference between model predicted and actual welfare values. Both actual and model predicted welfare are calculated using the parameter estimates from the structural model. Actual welfare is calculated using actual values of actions and states in the data. Model predicted welfare is calculated using model predicted actions and states generated from 100 simulation runs of the open access period. The standard errors for the model predicted welfare values and for the difference between model predicted and actual welfare values are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to the difference between model predicted and actual welfare values denote the significance level of the difference between model predicted and actual average annual welfare. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table A.6: Model Predicted vs. Actual Average Annual Profits, 2004-2013

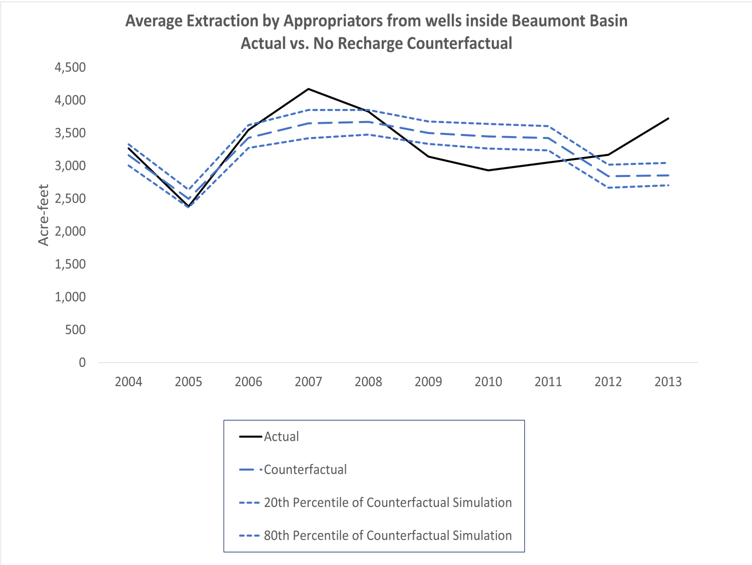
| Player | Model Predicted Minus Actual Data | | |
|---|---|---|---|
| | *Profits (dollars)* | *Revenues (dollars)* | *Costs (dollars)* |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | -0.1 million | 0 million | 0.1 million |
| City of Banning | -0.1 million | 0 million | 0.1 million |
| South Mesa Water Company | 0 million | 0 million | 0.02 million |
| Yucaipa Valley Water District | -0.2 million | -0.1 million | 0.1 million |
| **Total Appropriator** | **-0.4 million** | **0 million** | **0.3 million** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 2 thousand | 9.7 thousand | 7.7 thousand |
| Riedman | 0.8 thousand | 3.7 thousand | 2.9 thousand |
| **Total Farmers in Beaumont Basin** | **2.9 thousand** | **13.4 thousand** | **10.5 thousand** * |
| Farmers outside Beaumont Basin | | | |
| Dowling | -0.3 thousand | 0.4 thousand | 0.6 thousand *** |
| Illy | 0.3 thousand | 1.5 thousand | 1.2 thousand ** |
| Summit | -1.5 thousand | 0.8 thousand | 2.2 thousand *** |
| Hudson | 0.8 thousand | 3.7 thousand | 2.9 thousand * |
| **Total Farmers outside Beaumont Basin** | **-0.6 thousand** | **6.4 thousand** | **6.9 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | 3.5 thousand | 5 thousand | 1.5 thousand |
| Southern California PGA | -7.1 thousand | -3.9 thousand | 3.2 thousand |
| Oak Valley Partners | 0.2 thousand | 1.7 thousand | 1.4 thousand |
| Plantation on the Lake | -0.3 thousand | 1.2 thousand ** | 1.5 thousand * |
| Sharondale Mesa Owners Association | 0 thousand | 1.2 thousand ** | 1.1 thousand * |
| **Total Recreational Users** | **-3.6 thousand** | **5.1 thousand** | **8.7 thousand** |

Notes: Average annual profits, revenues, and costs are the present discounted value of the entire stream over the period 2004-2013 of profits, revenues, and costs, respectively, divided by the number of years. For farmers and recreational users, average annual welfare is equal to average annual profits. For appropriators, profits are the profits from water sales given by the water sale revenues minus extraction costs, while the per-payoffs are a weighted quadratic function of consumer surplus and the profits from water sales. Both actual and model predicted profit components are calculated using the parameter estimates from the structural model. Actual profit components are calculated using actual values of actions and states in the data. Model predicted profit components are calculated using model predicted actions and states. Table reports the difference between model predicted and actual values of the respective average annual profit component. Significance stars denote the significance level of the difference between model predicted and actual values of the respective average annual profit component. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

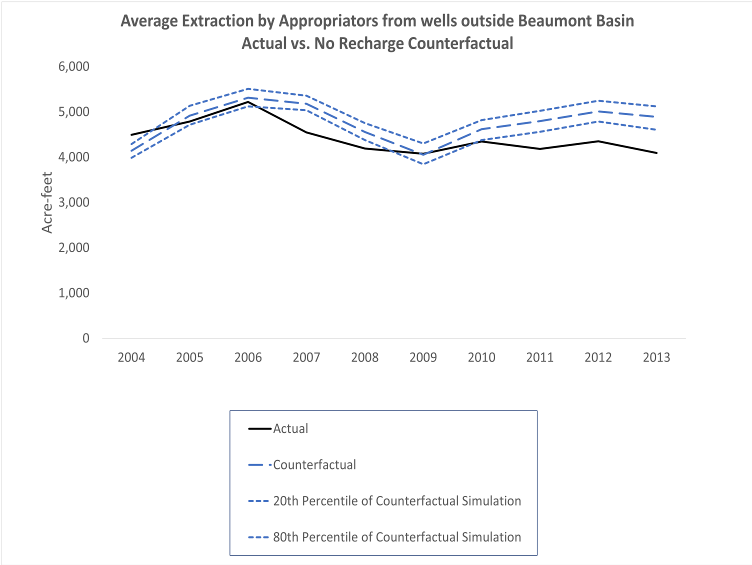
Table A.7: Model Predicted vs. Actual Social Welfare, 2004-2013

| | Actual | Model Predicted | Model Predicted Minus Actual |
|---|---|---|---|
| | | *Average Annual Profits (dollars)* | |
| Appropriator profits | -3.9 million | -4.3 million | -0.4 million |
| Farmer profits inside Beaumont Basin | 22.8 thousand | 25.6 thousand | 2.8 thousand |
| Farmer profits outside Beaumont Basin | 14.3 thousand | 13.7 thousand | -0.6 thousand |
| Recreational user profits | 4.8 thousand | 0.8 thousand | -4 thousand |
| **Total Profits** | **-3.89 million** | **-4.26 million** | **-0.37 million** |
| | | *Average Annual Consumer Surplus (dollars)* | |
| Beaumont-Cherry Valley Water District | 7.8 million | 8.7 million | 0.9 million * |
| City of Banning | 7.1 million | 7.9 million | 0.8 million *** |
| South Mesa Water Company | 2.6 million | 2.8 million | 0.2 million *** |
| Yucaipa Valley Water District | 12 million | 13.3 million | 1.3 million *** |
| **Total Consumer Surplus** | **29.5 million** | **32.7 million** | **3.2 million *** ** |
| | | *Average Annual Value of Property Rights (dollars)* | |
| Beaumont-Cherry Valley Water District | -8.8 thousand | -9.8 thousand | -1.1 thousand |
| City of Banning | -2.3 thousand | -2.7 thousand | -0.4 thousand |
| South Mesa Water Company | -3.1 thousand | -3.2 thousand | -0.1 thousand |
| Yucaipa Valley Water District | -3.3 thousand | -3.7 thousand | -0.4 thousand |
| Farmers inside Beaumont Basin | -0.6 thousand | -0.8 thousand | -0.1 thousand |
| Recreational Users | -3 thousand | -3.3 thousand | -0.4 thousand |
| **Total Value of Property Rights** | **0 million** | **0 million** | **0 million** |
| | | *Average Annual Value of Imported Water (dollars)* | |
| Beaumont-Cherry Valley Water District | 784.7 thousand | 858.9 thousand | 74.2 thousand |
| City of Banning | 187.7 thousand | 210.8 thousand | 23.1 thousand |
| South Mesa Water Company | N/A | N/A | N/A |
| Yucaipa Valley Water District | 969.1 thousand | 1063.2 thousand | 94.1 thousand |
| **Total Value of Imported Water** | **1.9 million** | **2.1 million** | **191.4 thousand** |
| **Social Welfare** | **27.6 million** | **30.6 million** | **3 million *** ** |

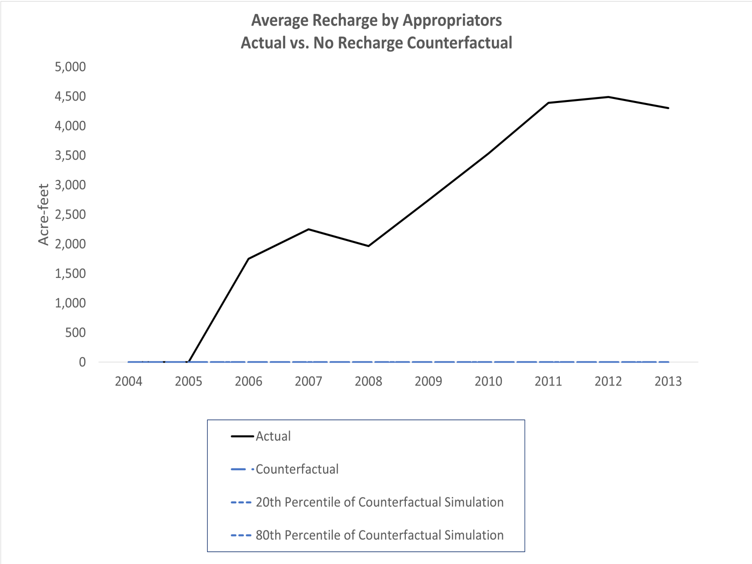
Notes: Components of social welfare are the present discounted value of the entire stream of per-period payoffs related to each component over the period 2004-2013. Average annual values of these components are equal to the total value of the component divided by the number of years. Producer surplus is equal to the sum of profits from groundwater extraction by each group of players, and the value of holding property rights for appropriators. Consumer surplus is equal to the sum of consumer surplus for each appropriator in the sample and is determined by the residential demand model. It is not weighted by parameters in the payoff function of the appropriator. Social welfare is equal to the sum of producer surplus and consumer surplus. Difference from actual' is the difference between model predicted and actual component values. Actual values are calculated using actual values of actions and states in the data. Model predicted values are calculated using model predicted actions and states generated from 100 simulation runs of the open access period. The standard errors for the difference between model predicted and actual welfare values are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to the difference between model predicted and actual values denote the significance level of the difference between model predicted and actual average annual values. Significance codes: *** p<0.001, ** p<0.01, * p<0.05



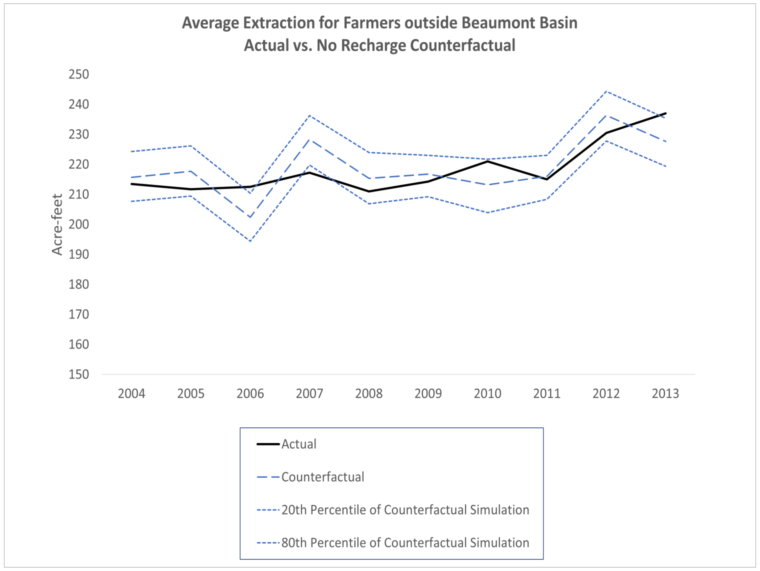

(a) Appropriator Extraction
inside Beaumont Basin




(b) Appropriator Extraction
outside Beaumont Basin

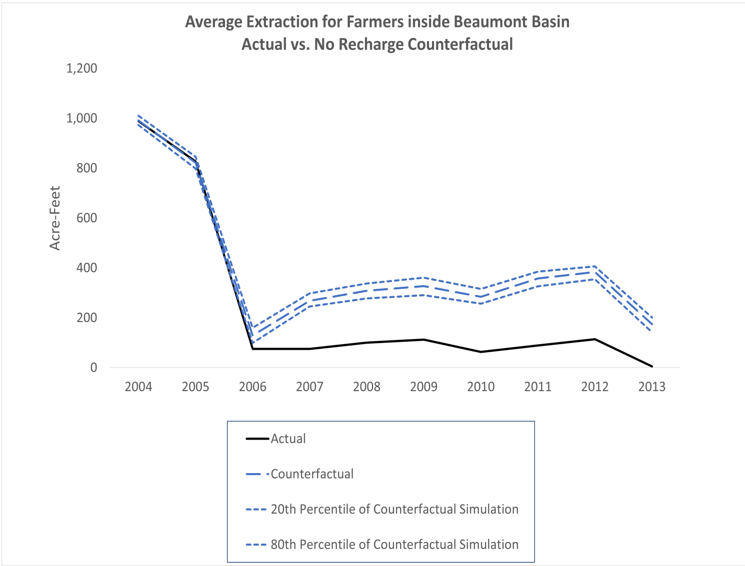



(c) Appropriator
Recharge

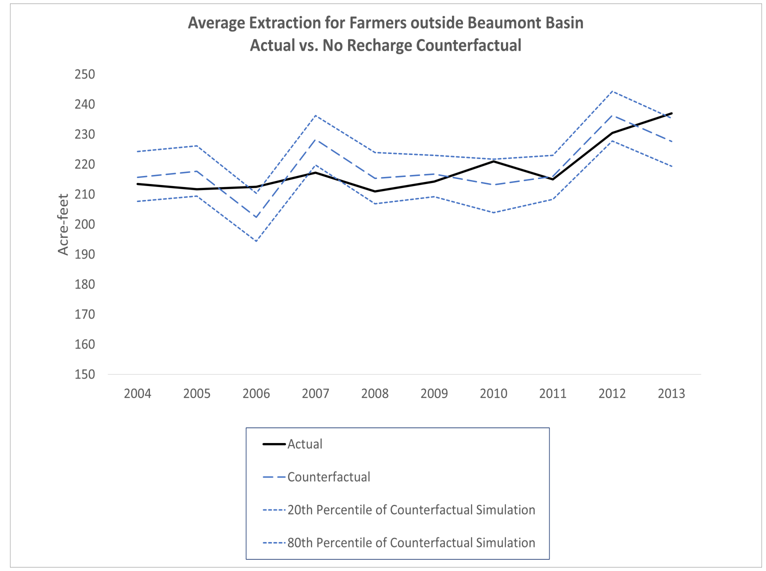



(d) Appropriator
Filtered Sales

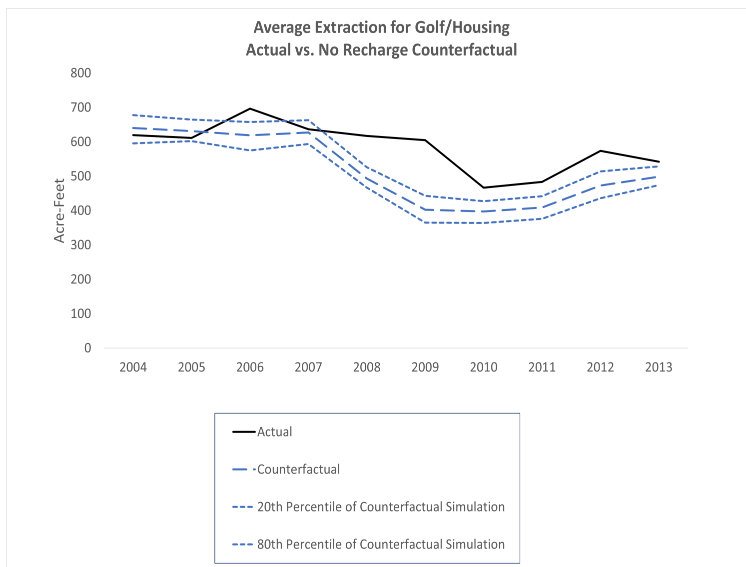
Figure A.10: No Recharge Counterfactual Comparison: Appropriator Behavior




(a) Farmer Extraction
inside Beaumont Basin

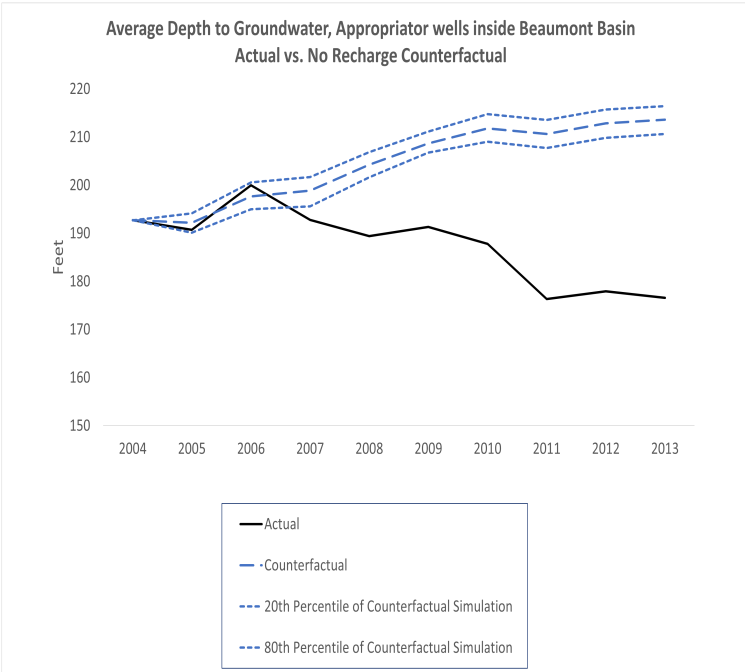



(b) Farmer Extraction
outside Beaumont Basin

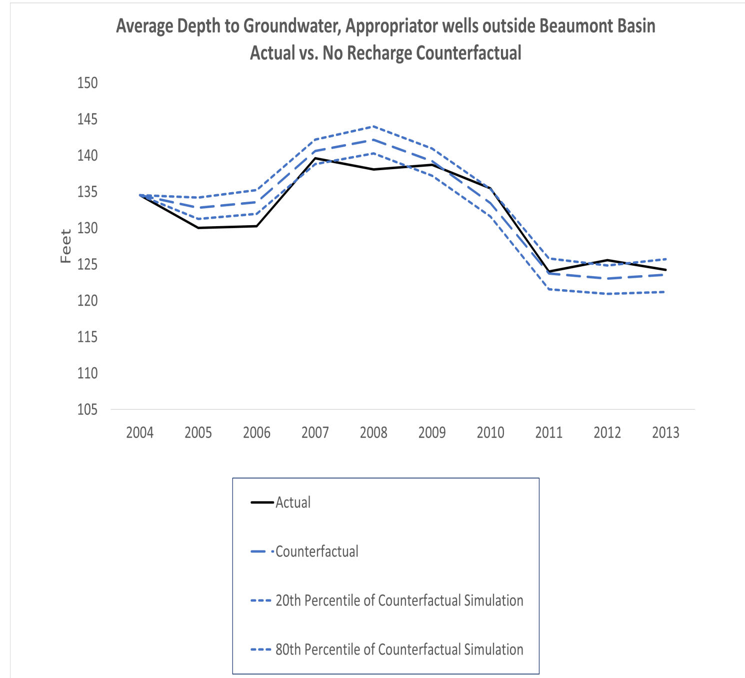



(c) Recreational User
Extraction

Figure A.11: No Recharge Counterfactual Comparison: Overlyer Behavior

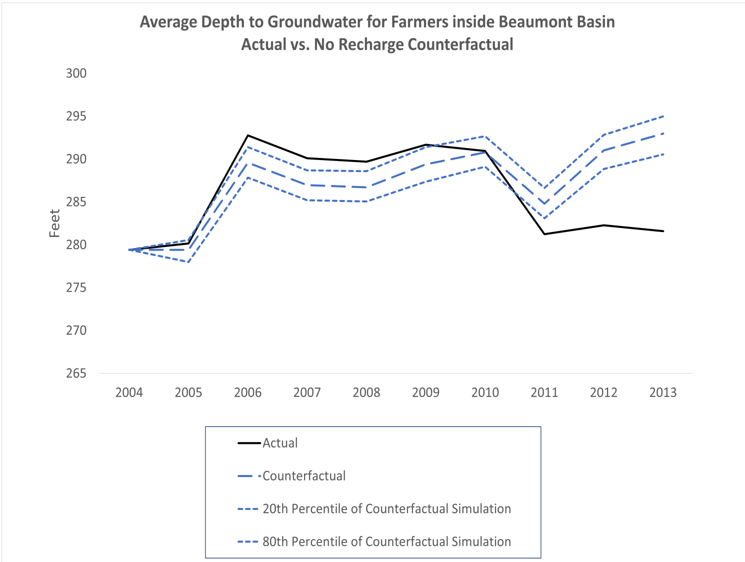



(a) Appropriator Depth to Groundwater inside Beaumont Basin

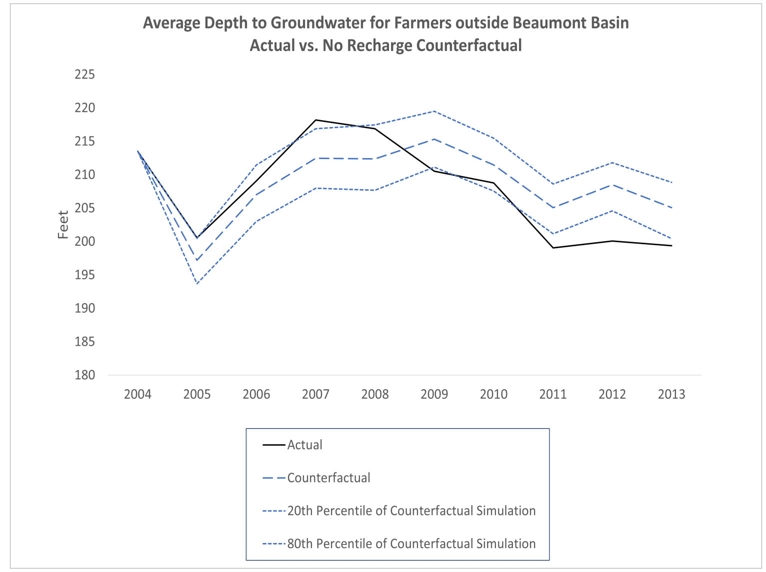



(b) Appropriator Depth to Groundwater outside Beaumont Basin

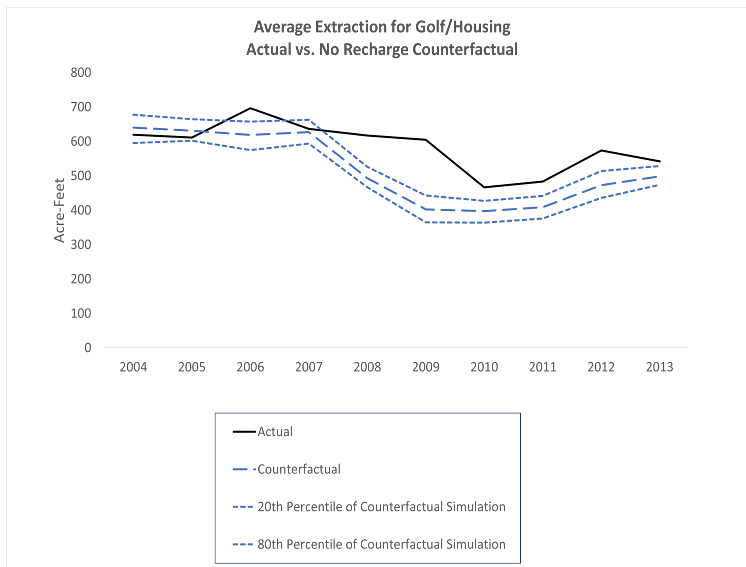
Figure A.12: No Recharge Counterfactual Comparison: Appropriator Depth to Groundwater




(a) Farmer Depth
to Groundwater
inside Beaumont Basin

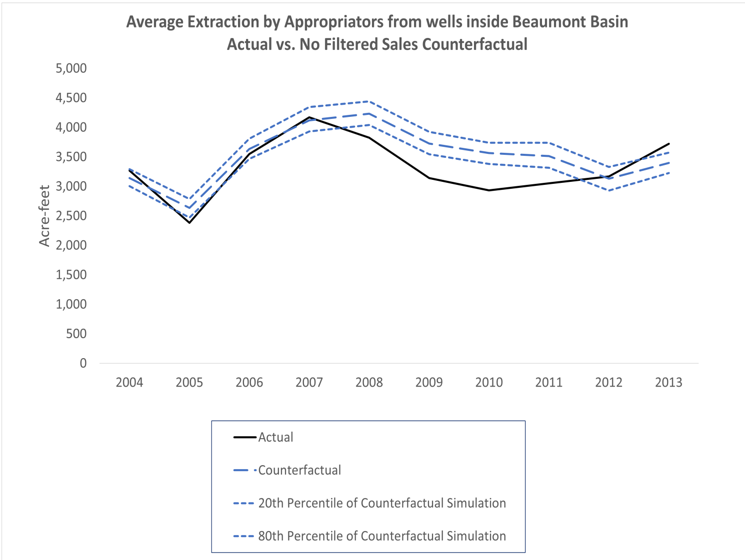



(b) Farmer Depth
to Groundwater
outside Beaumont Basin

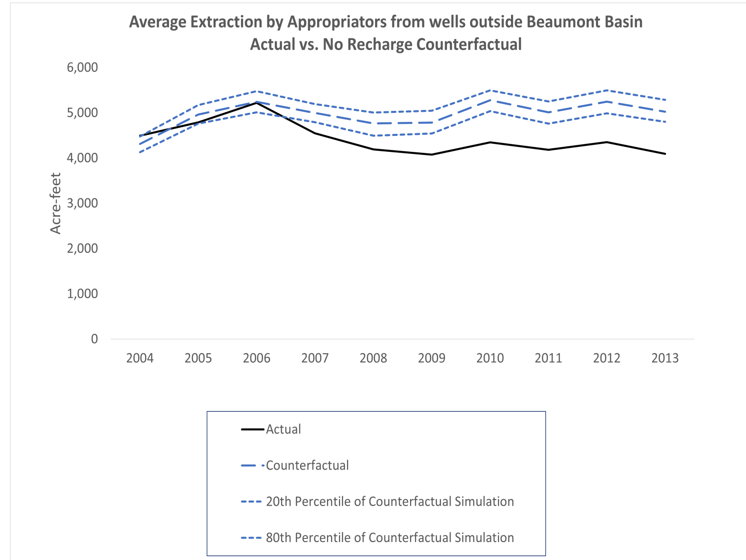



(c) Recreational User
Depth to Groundwater

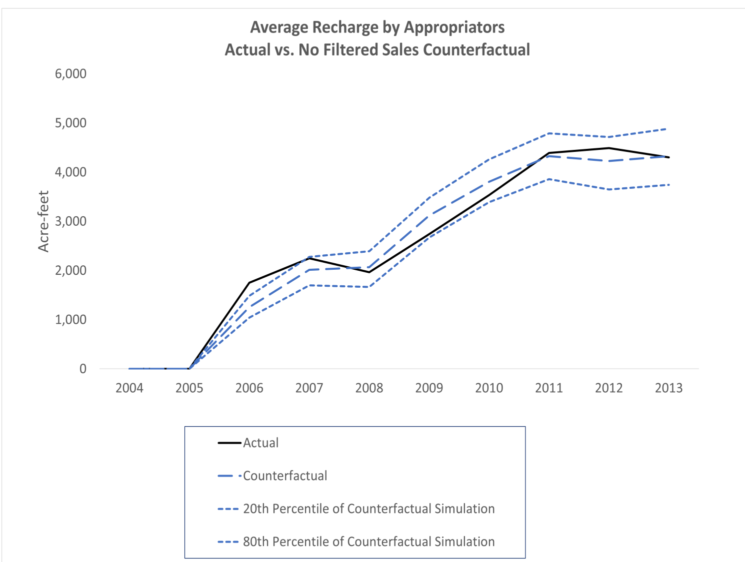
Figure A.13: No Recharge Counterfactual Comparison: Overlyer Depth to Groundwater



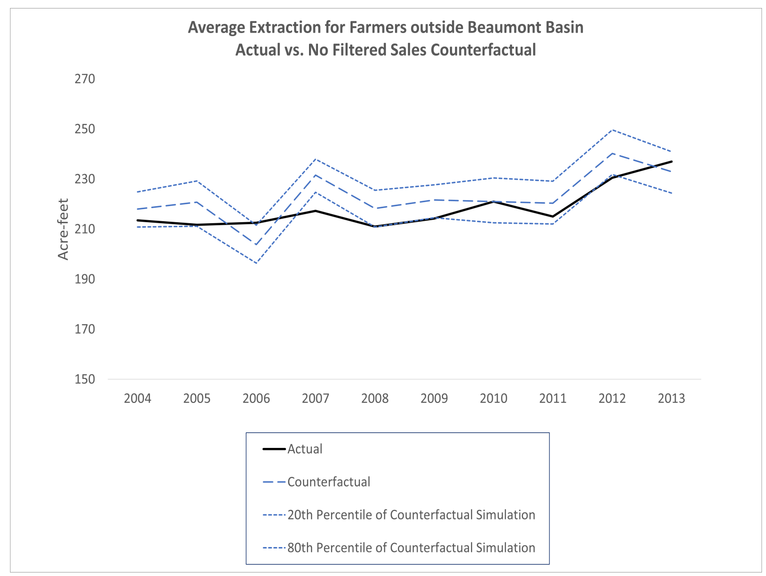

(a) Appropriator Extraction inside Beaumont Basin




(b) Appropriator Extraction outside Beaumont Basin

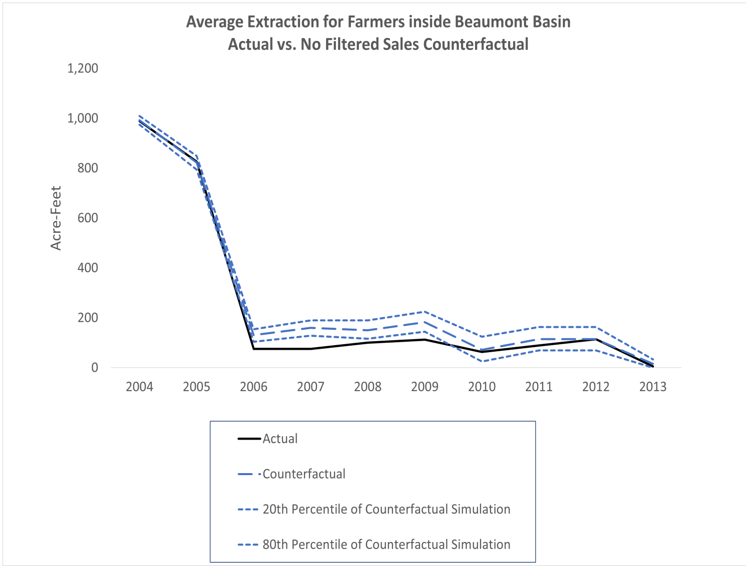



(c) Appropriator Recharge

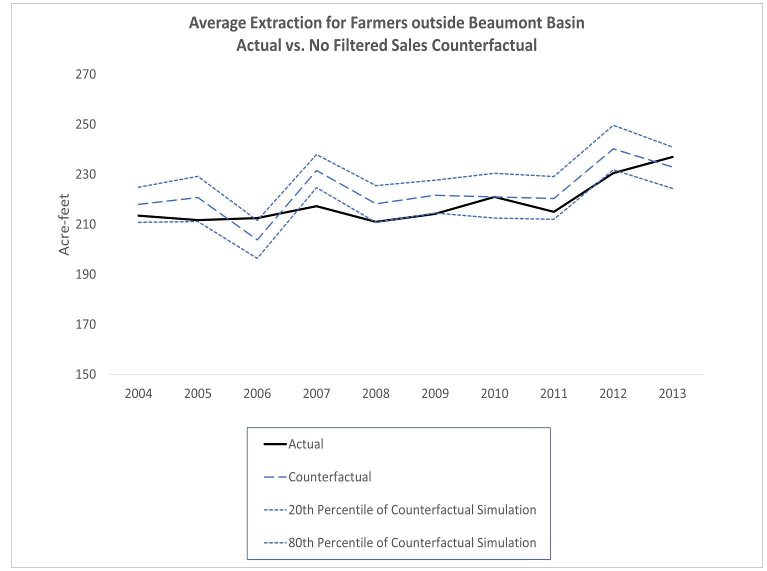



(d) Appropriator Filtered Sales

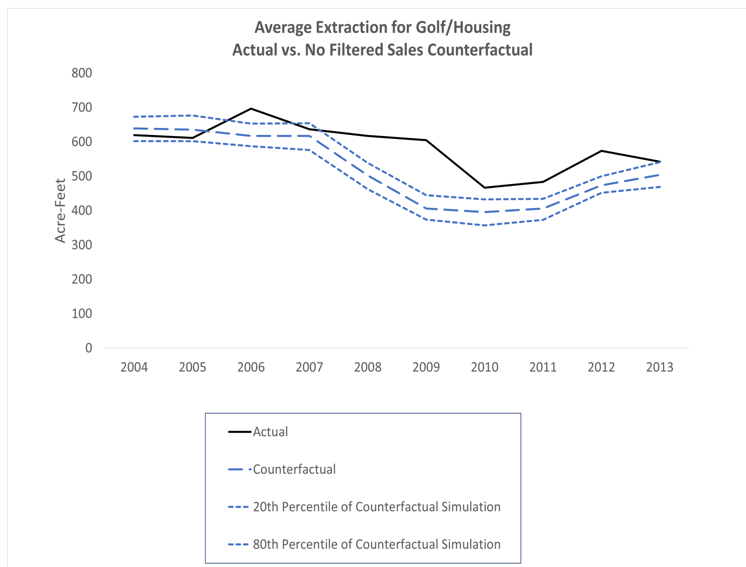
Figure A.14: No Filtered Sales Counterfactual Comparison: Appropriator Behavior




(a) Farmer Extraction inside Beaumont Basin

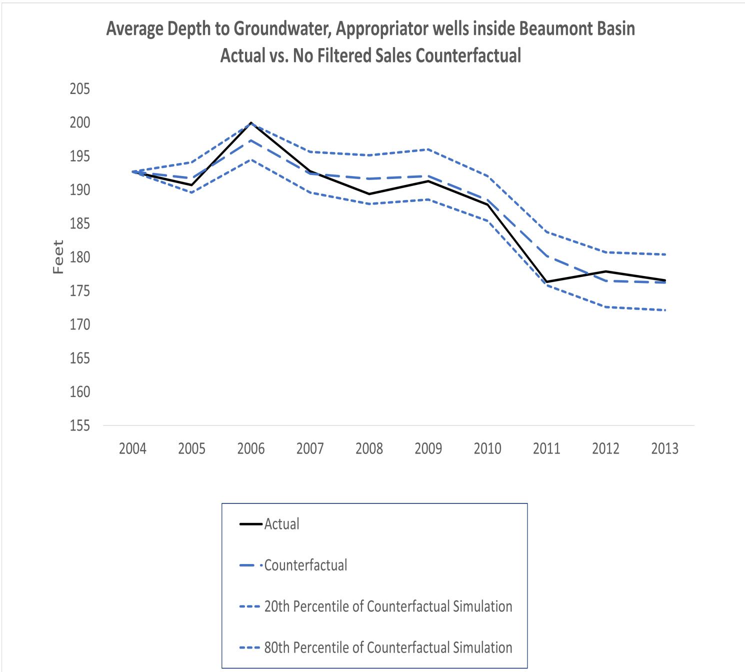



(b) Farmer Extraction outside Beaumont Basin

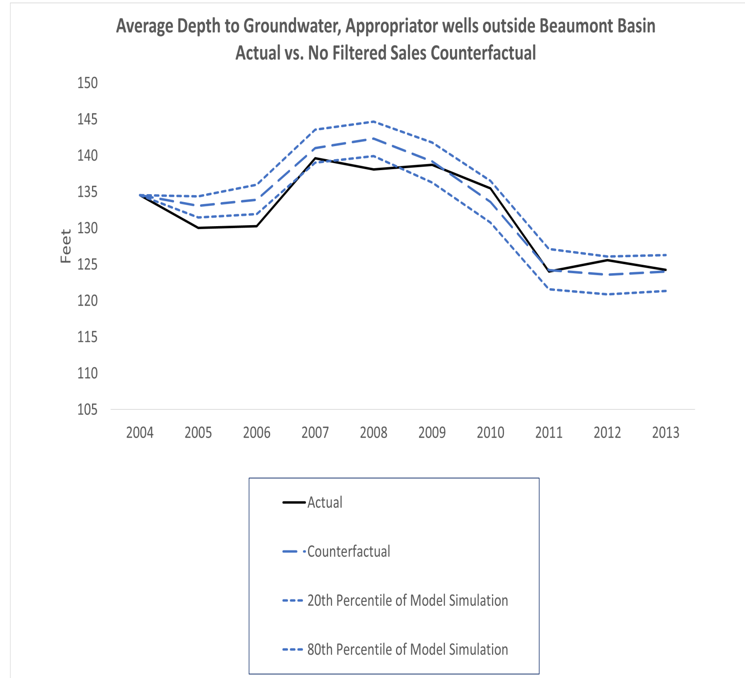



(c) Recreational User Extraction

Figure A.15: No Filtered Sales Counterfactual Comparison: Overlyer Behavior

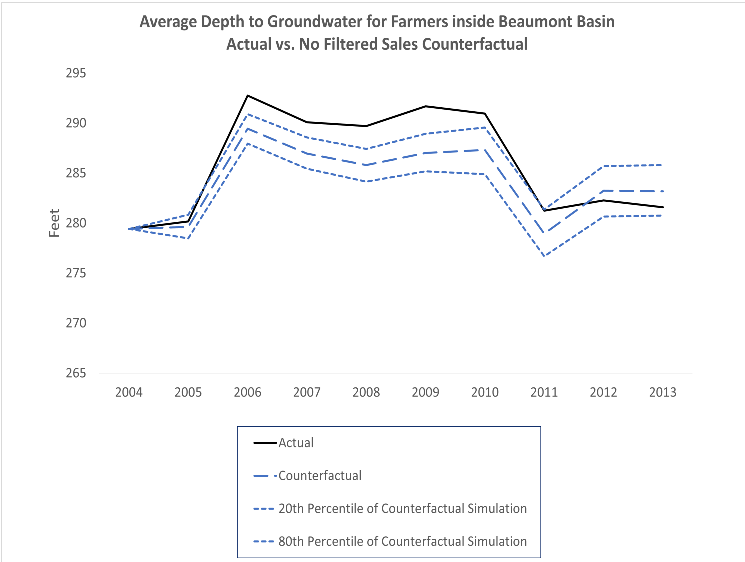



(a) Appropriator Depth to Groundwater inside Beaumont Basin

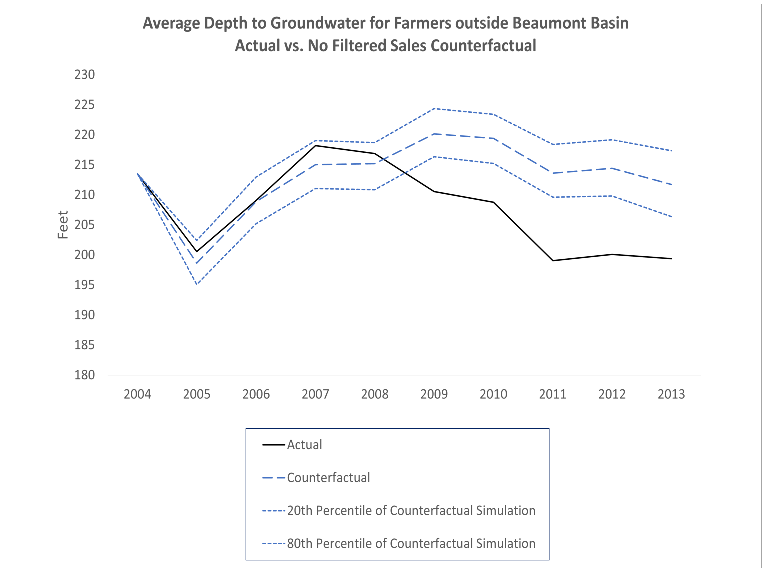



(b) Appropriator Depth to Groundwater outside Beaumont Basin

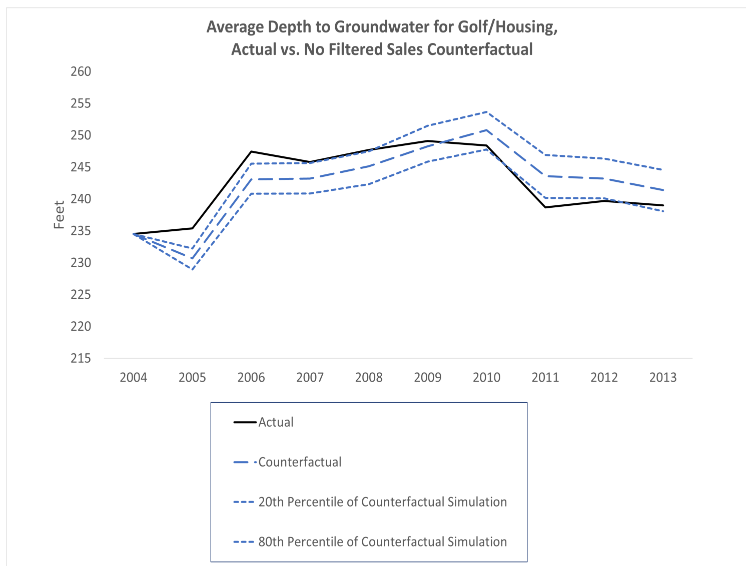
Figure A.16: No Filtered Sales Counterfactual Comparison: Appropriator Depth to Groundwater




(a) Farmer Depth to Groundwater inside Beaumont Basin

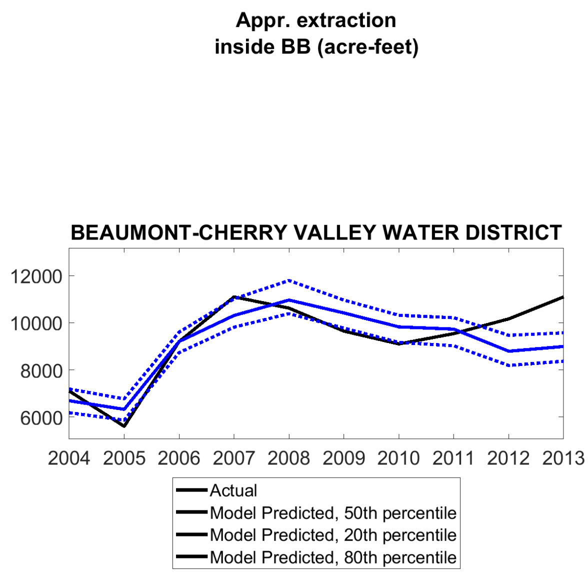



(b) Farmer Depth to Groundwater outside Beaumont Basin

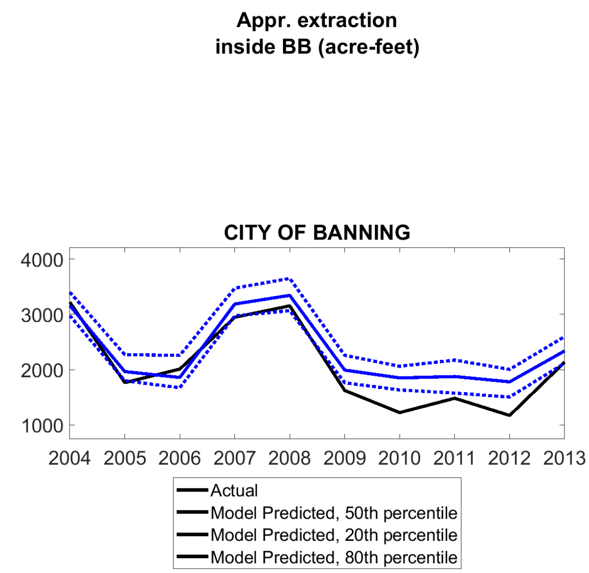



(c) Recreational User Depth to Groundwater

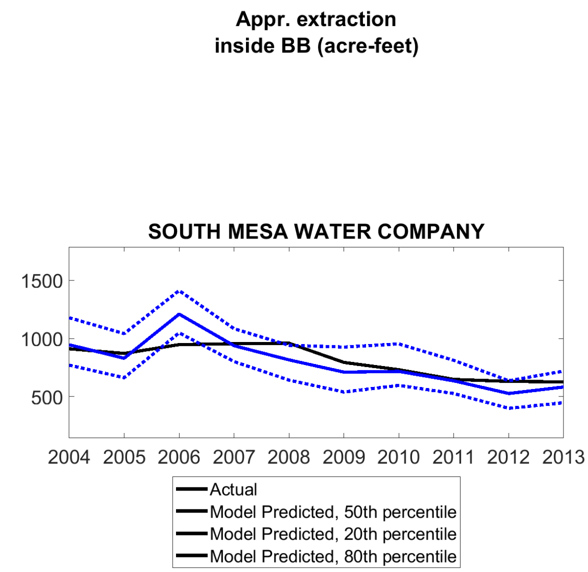
Figure A.17: No Filtered Sales Counterfactual Comparison: Overlyer Depth to Groundwater



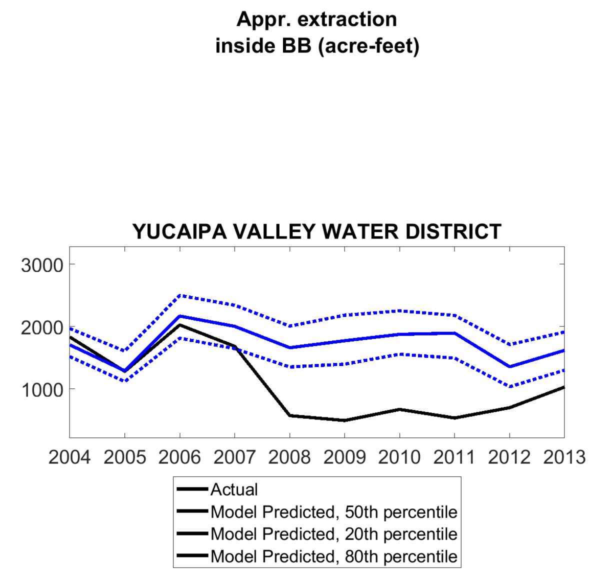

(a) Beaumont-Cherry Valley Water District




(b) City of Banning

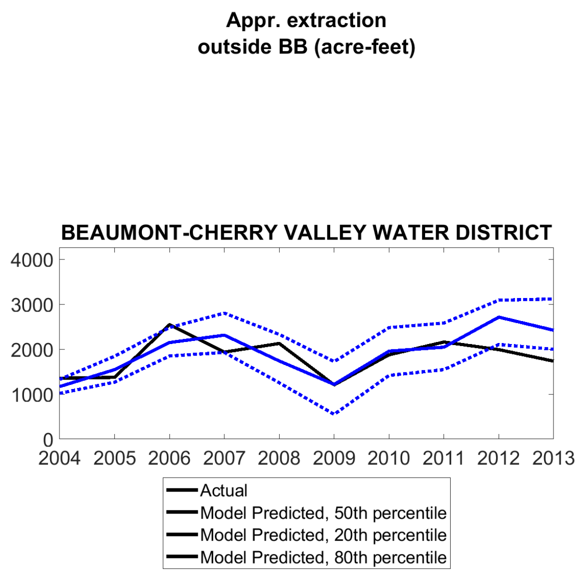



(c) South Mesa Water Company

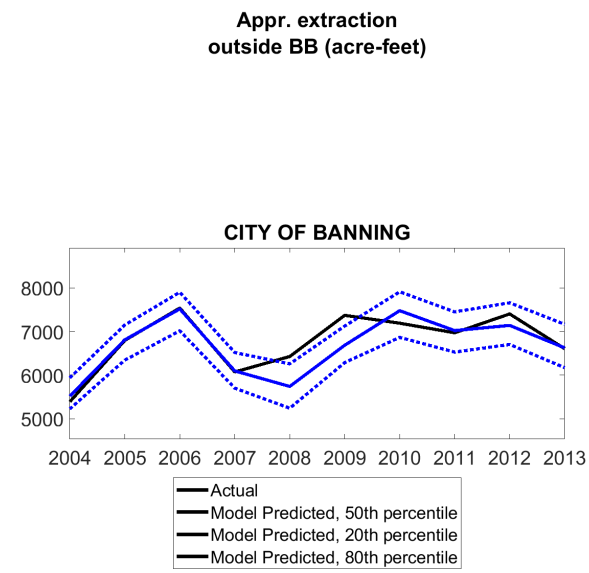



(d) Yucaipa Valley Water District

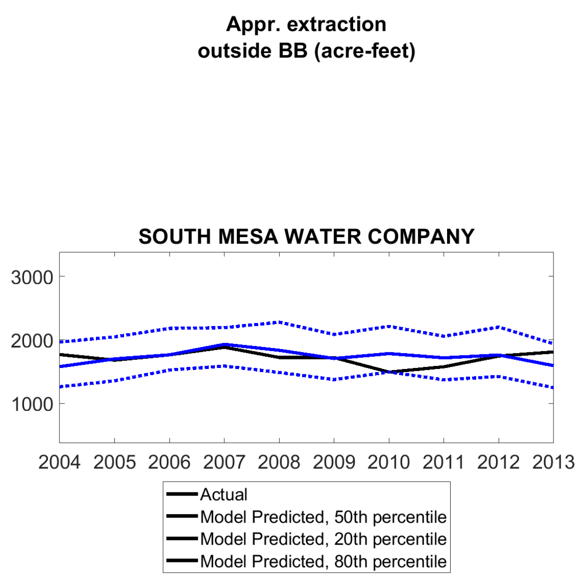
Figure A.18: No Filtered Sales Counterfactual Comparison: Appropriator Extraction in Beaumont Basin



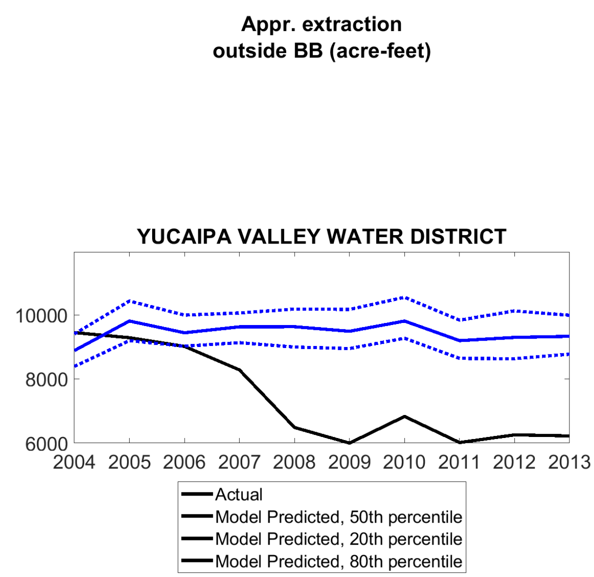

(a) Beaumont-Cherry Valley Water District




(b) City of Banning

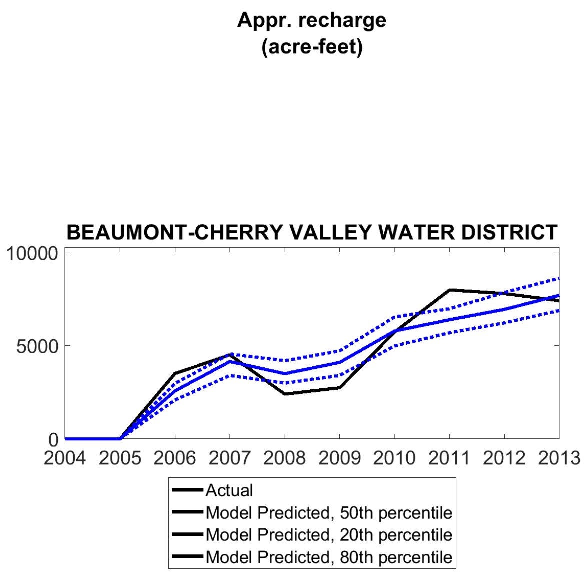



(c) South Mesa Water Company

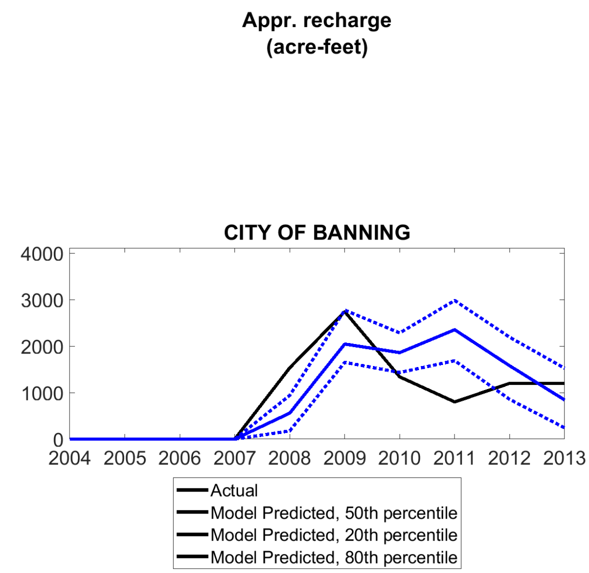



(d) Yucaipa Valley Water District

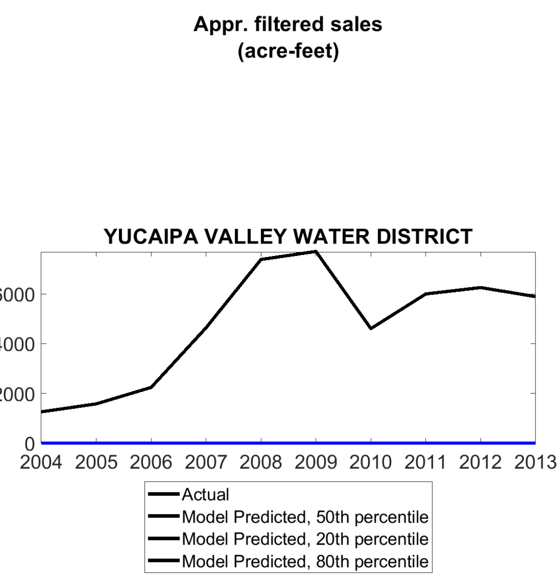
Figure A.19: No Filtered Sales Counterfactual Comparison: Appropriator Extraction outside Beaumont Basin




(a) Beaumont-Cherry Valley Water District

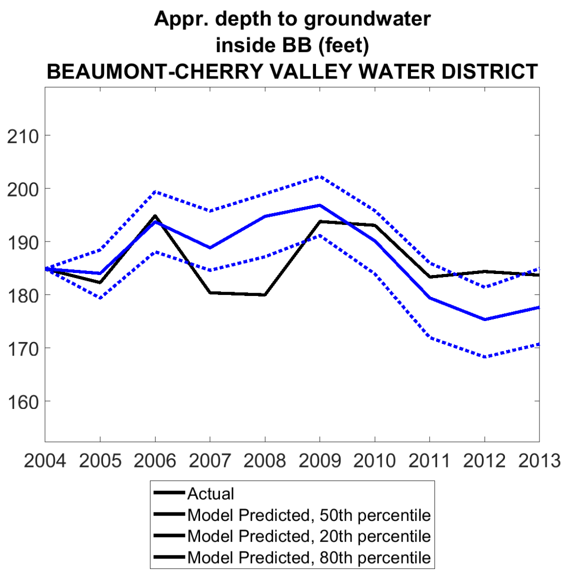



(b) City of Banning

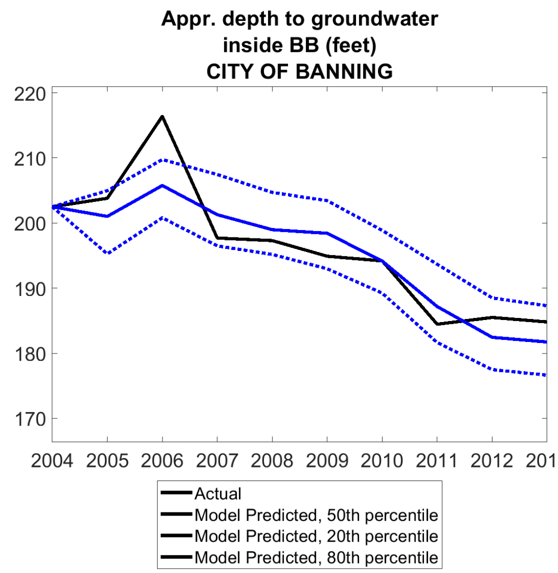



(c) Yucaipa Valley Water District

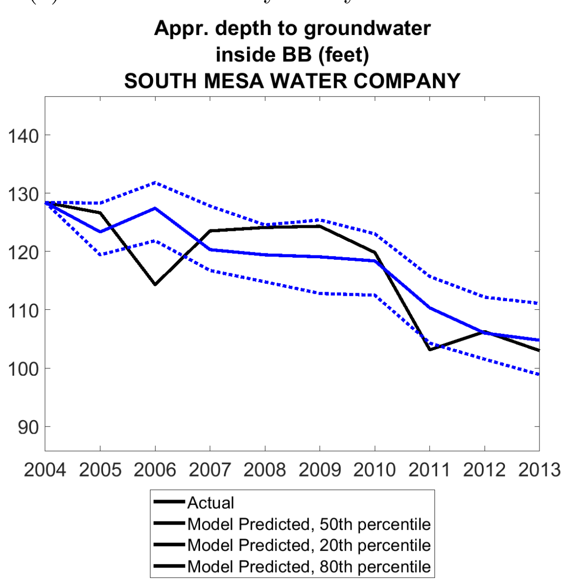
Figure A.20: No Filtered Sales Counterfactual Comparison: Appropriator Water Imports



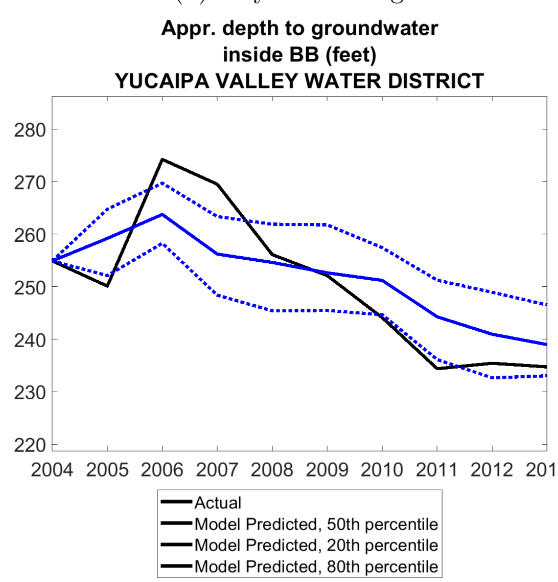

(a) Beaumont-Cherry Valley Water District




(b) City of Banning

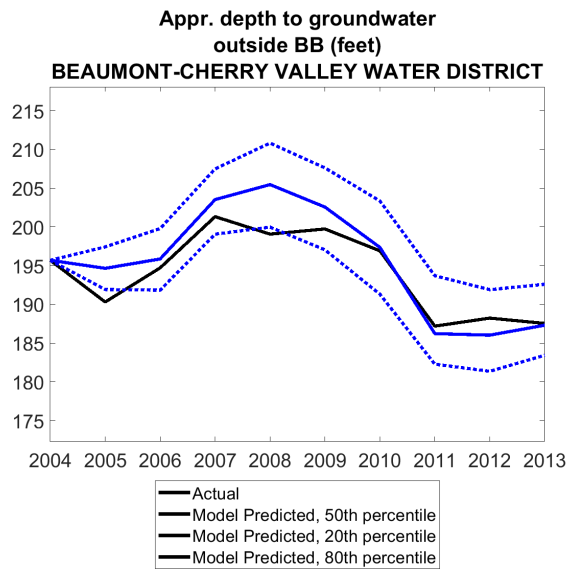



(c) South Mesa Water Company

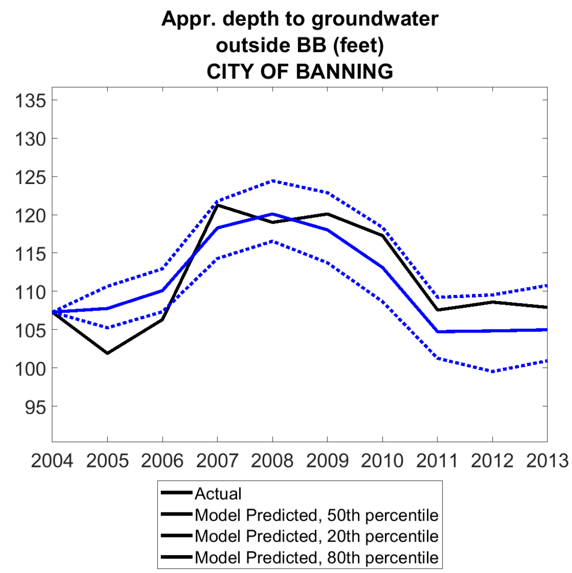



(d) Yucaipa Valley Water District

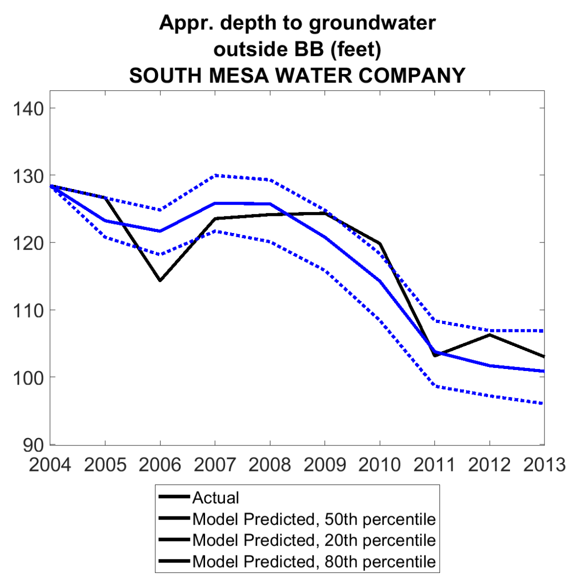
Figure A.21: No Filtered Sales Counterfactual Comparison: Appropriator Depth to Groundwater in Beaumont Basin



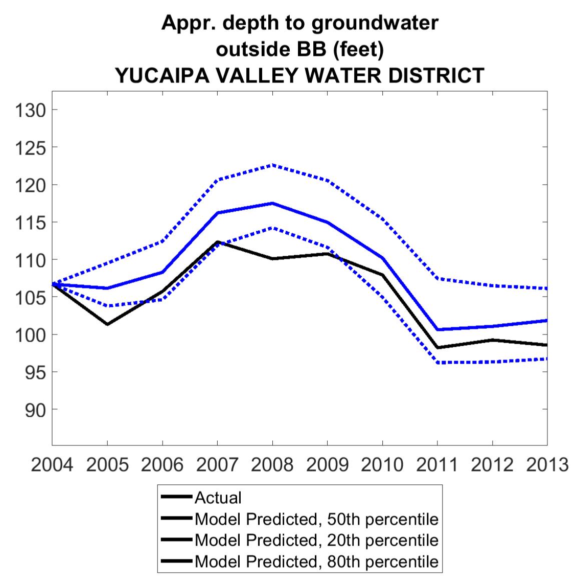

(a) Beaumont-Cherry Valley Water District




(b) City of Banning

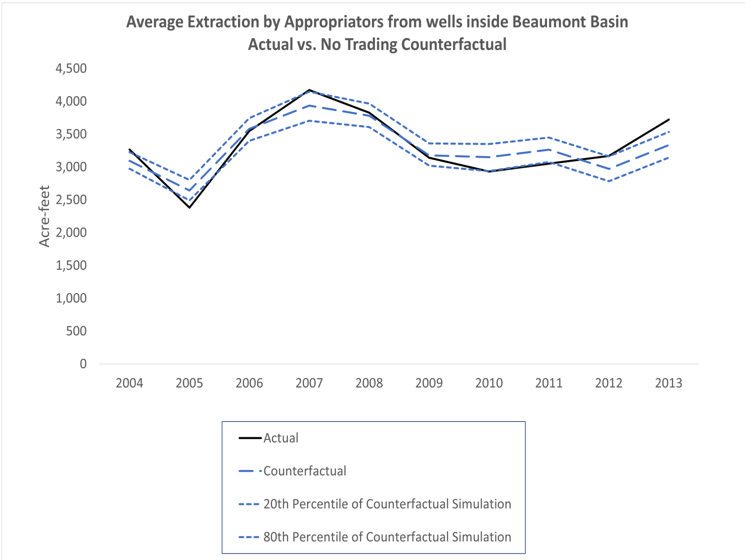



(c) South Mesa Water Company

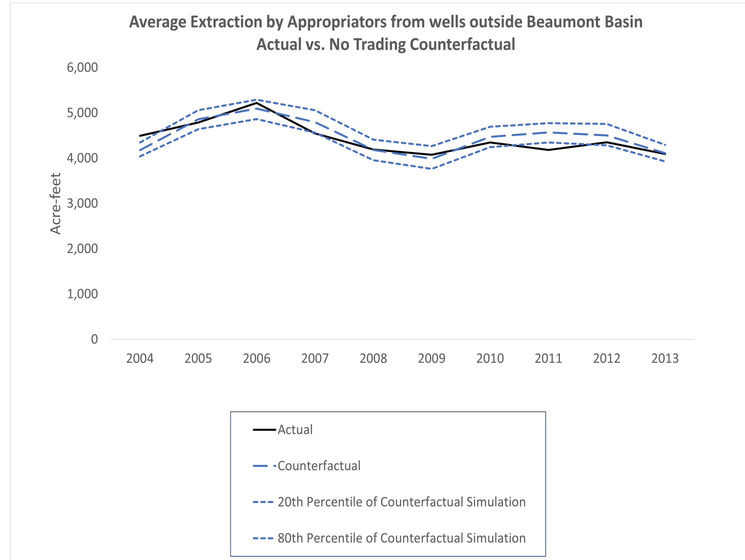



(d) Yucaipa Valley Water District

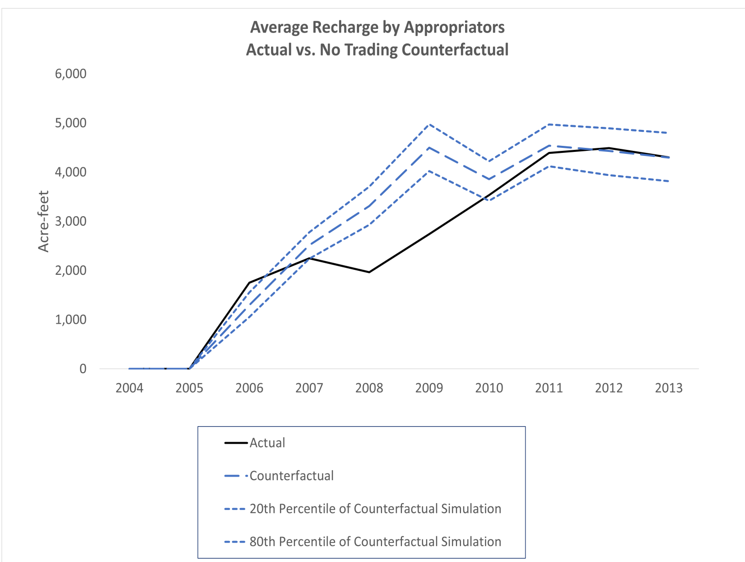
Figure A.22: No Filtered Sales Counterfactual Comparison: Appropriator Depth to Groundwater outside Beaumont Basin



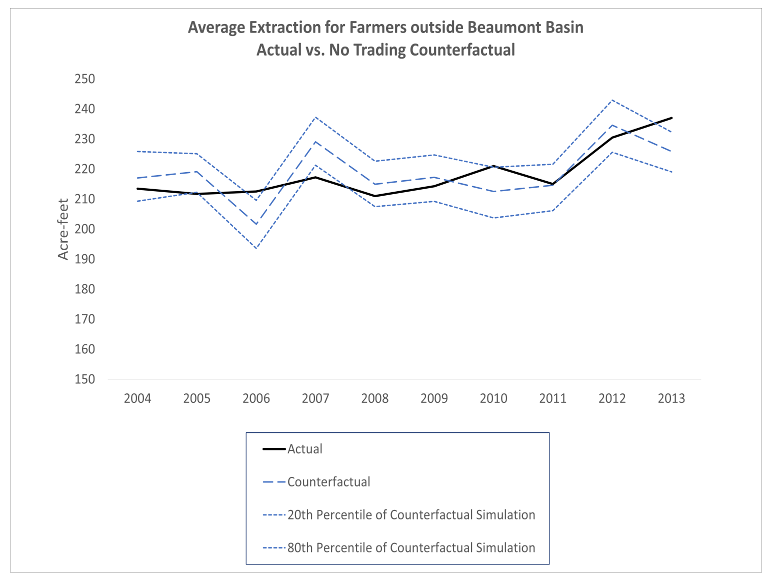

(a) Appropriator Extraction
inside Beaumont Basin




(b) Appropriator Extraction
outside Beaumont Basin

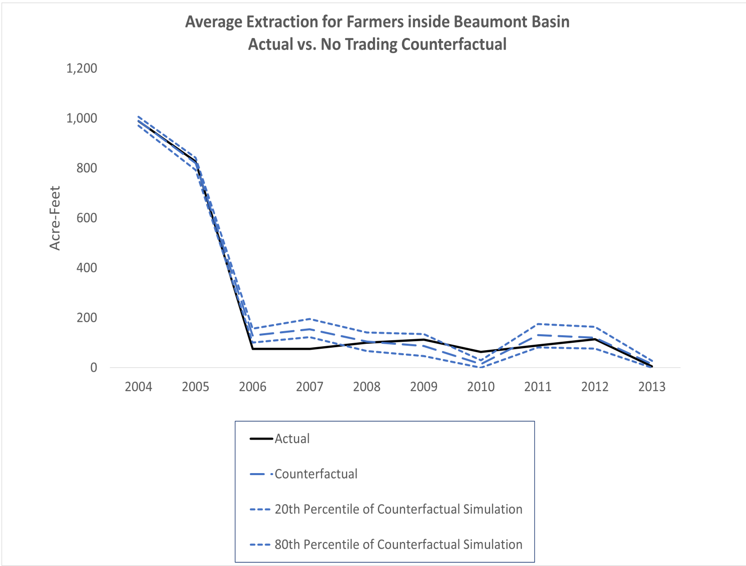



(c) Appropriator
Recharge

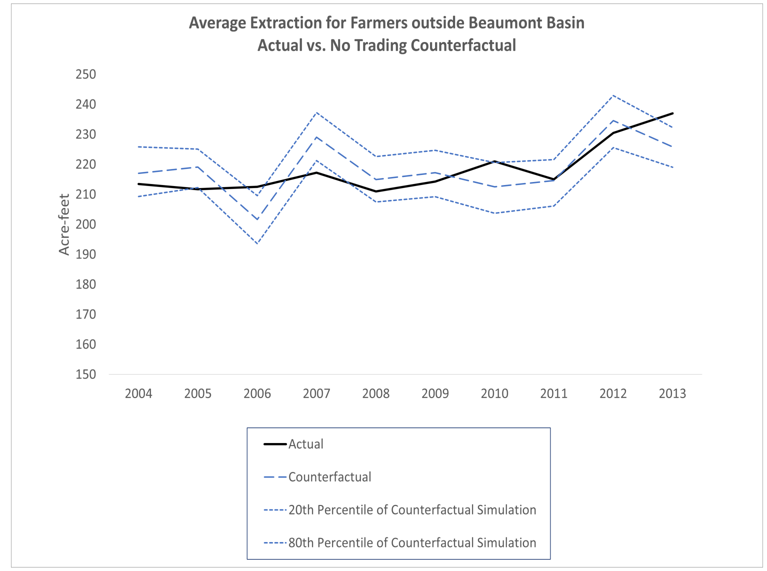



(d) Appropriator
Filtered Sales

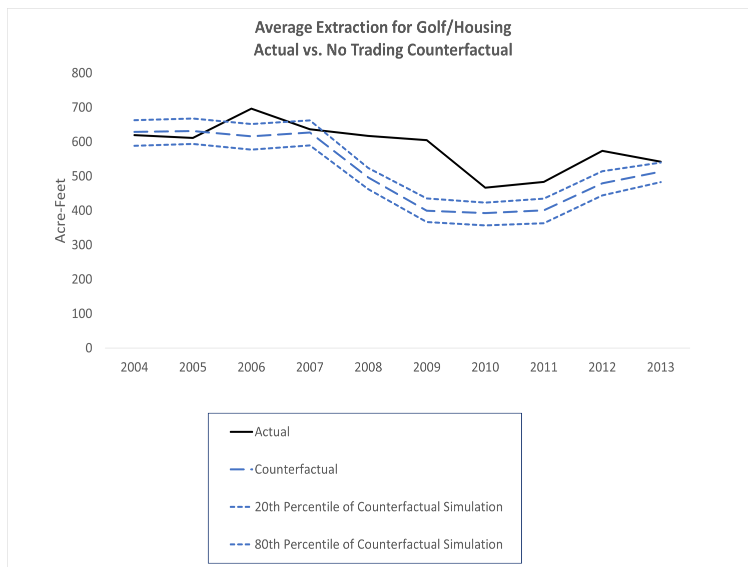
Figure A.23: No Trading Counterfactual Comparison: Appropriator Behavior




(a) Farmer Extraction inside Beaumont Basin

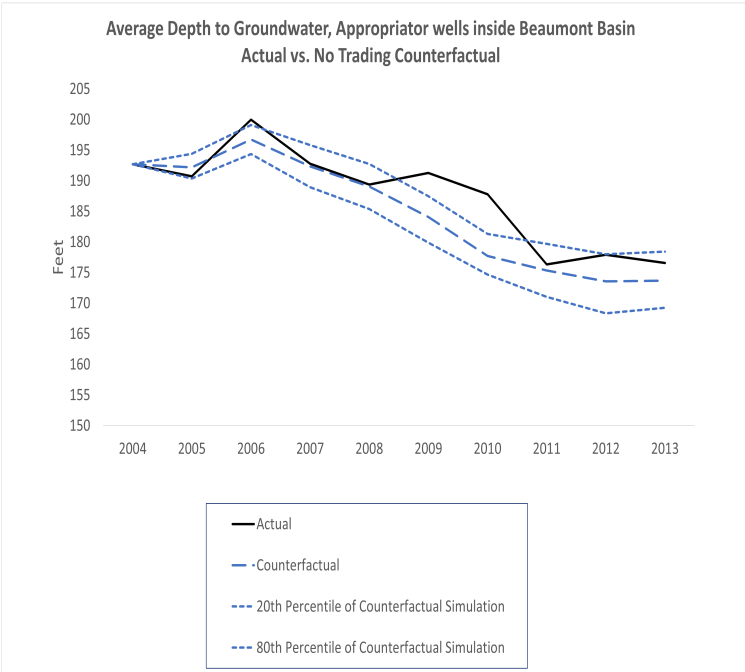



(b) Farmer Extraction outside Beaumont Basin

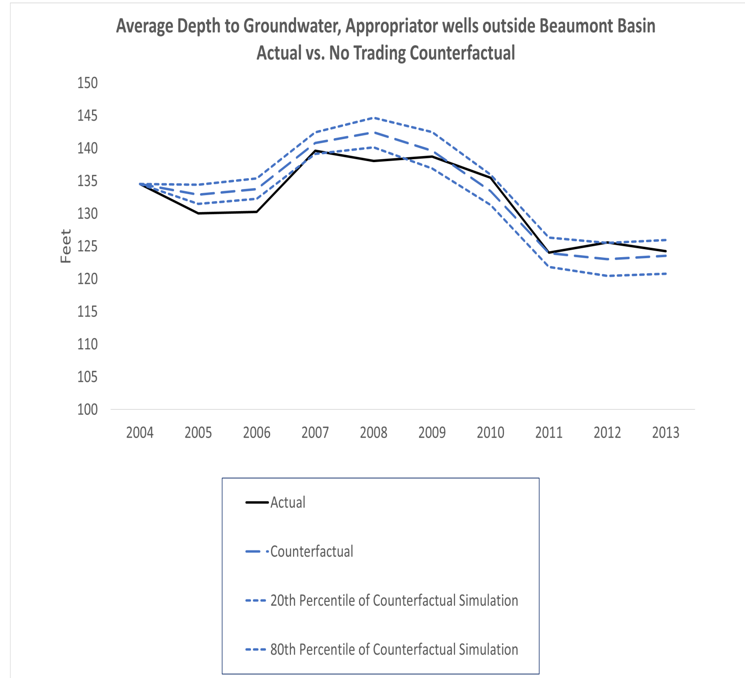



(c) Recreational User Extraction

Figure A.24: No Trading Counterfactual Comparison: Overlyer Behavior

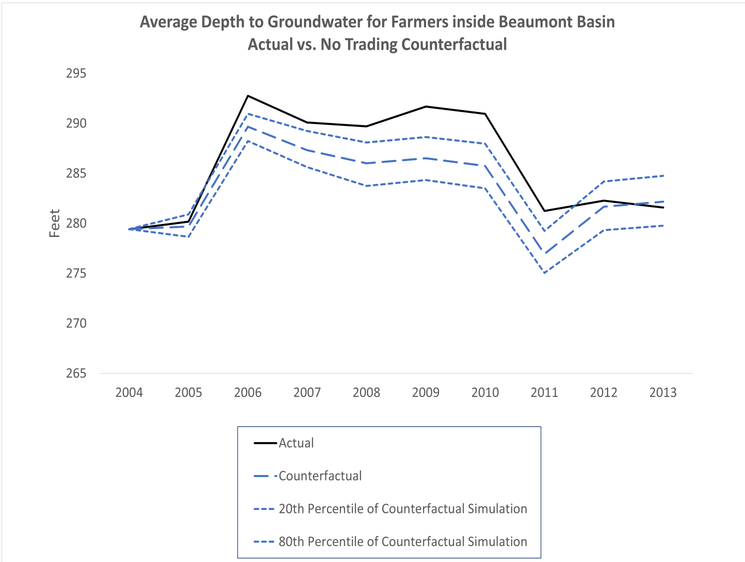



(a) Appropriator Depth to Groundwater inside Beaumont Basin

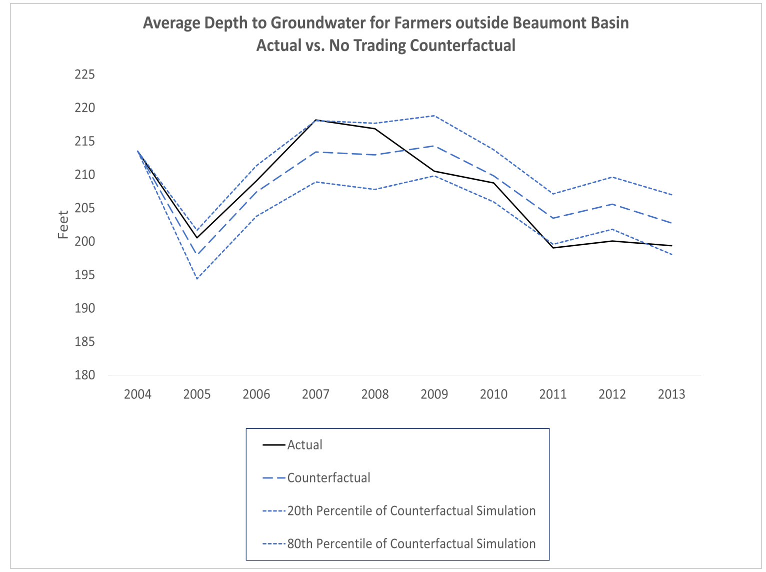



(b) Appropriator Depth to Groundwater outside Beaumont Basin

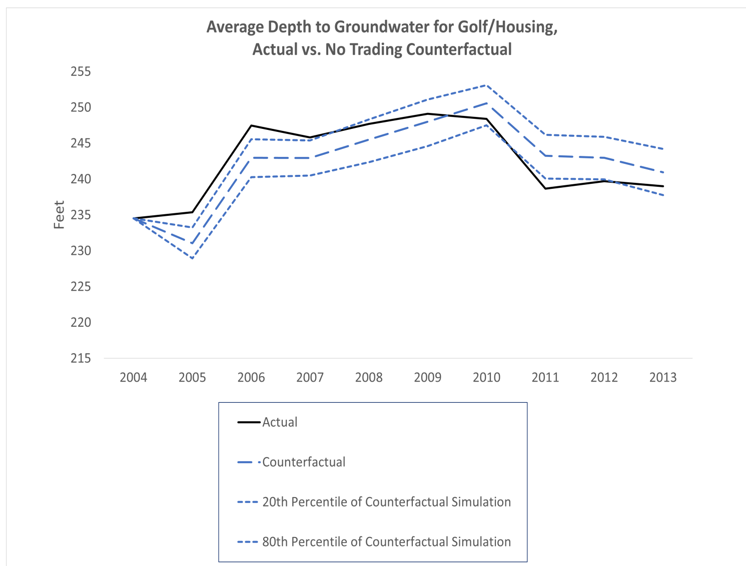
Figure A.25: No Trading Counterfactual Comparison: Appropriator Depth to Groundwater




(a) Farmer Depth to Groundwater inside Beaumont Basin

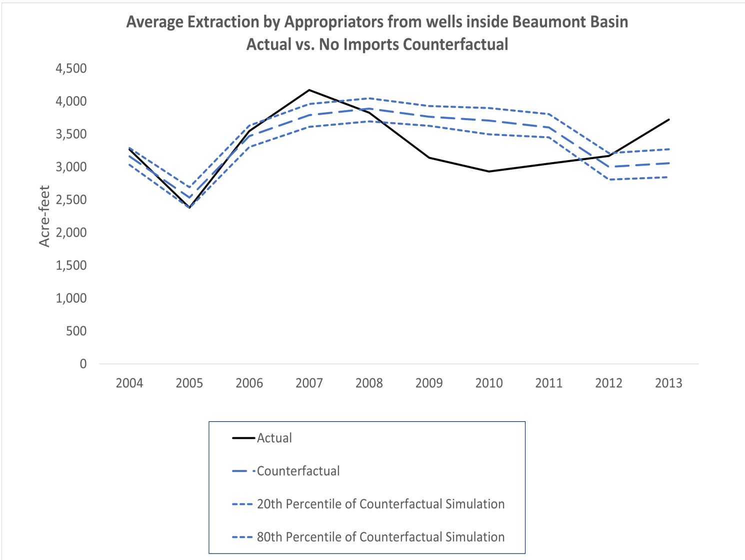



(b) Farmer Depth to Groundwater outside Beaumont Basin

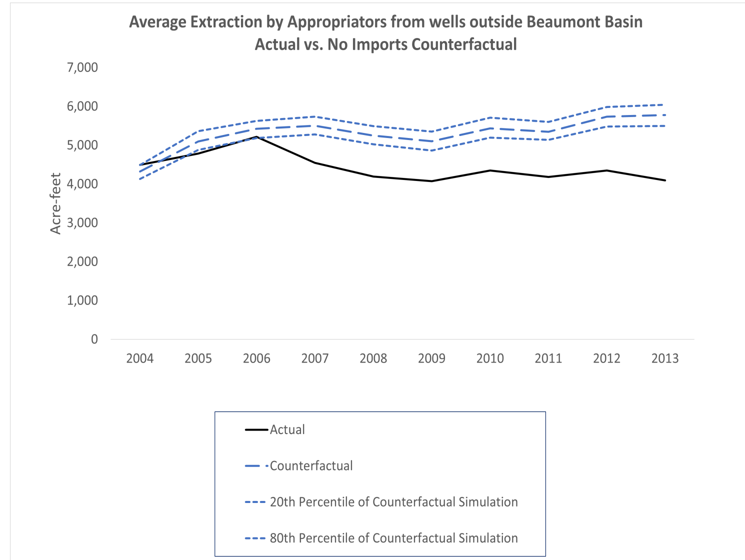



(c) Recreational User Depth to Groundwater

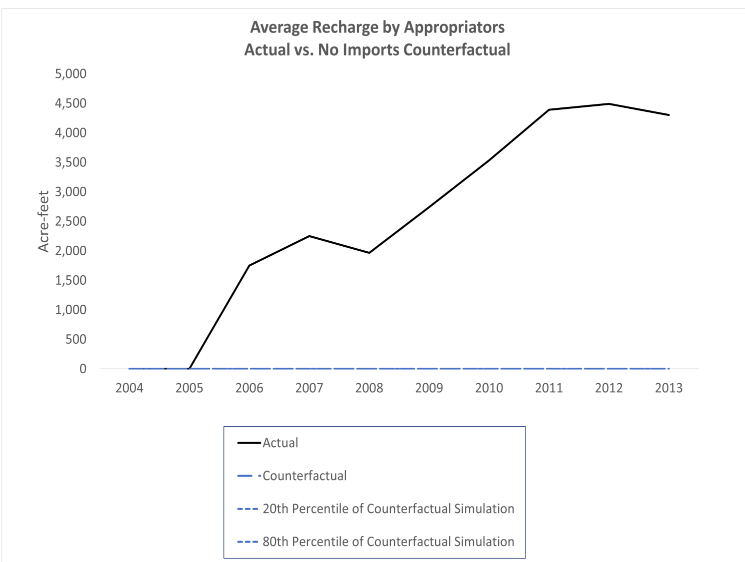
Figure A.26: No Trading Counterfactual Comparison: Overlyer Depth to Groundwater



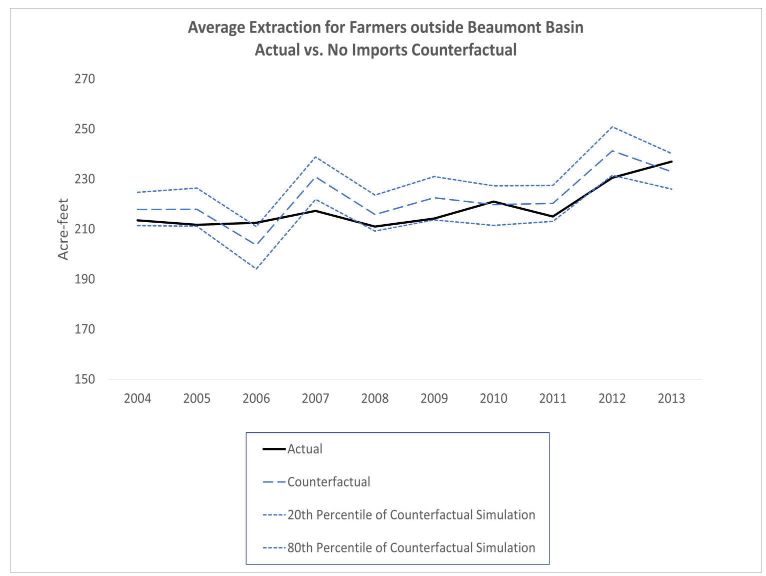

(a) Appropriator Extraction
inside Beaumont Basin




(b) Appropriator Extraction
outside Beaumont Basin

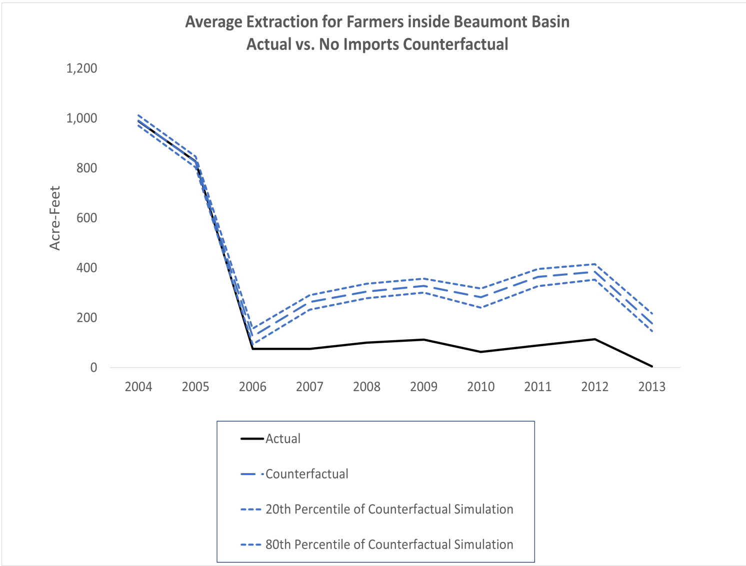



(c) Appropriator
Recharge

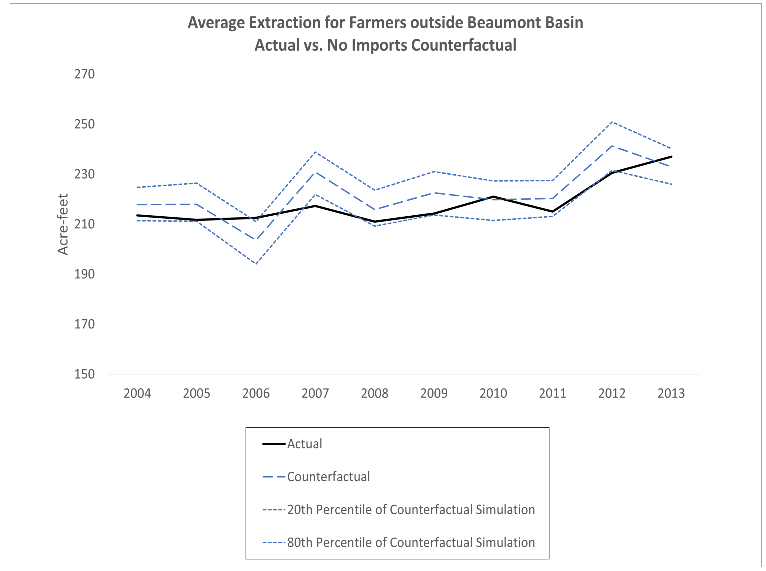



(d) Appropriator
Filtered Sales

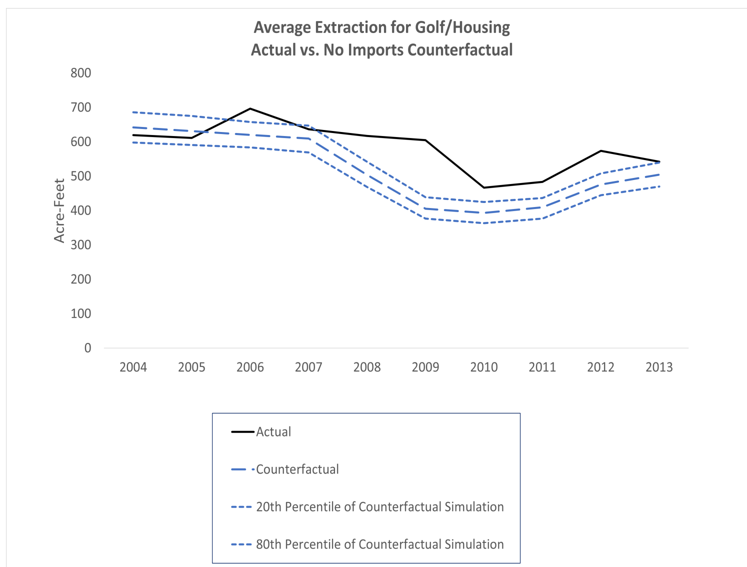
Figure A.27: No Imports Counterfactual Comparison: Appropriator Behavior




(a) Farmer Extraction inside Beaumont Basin

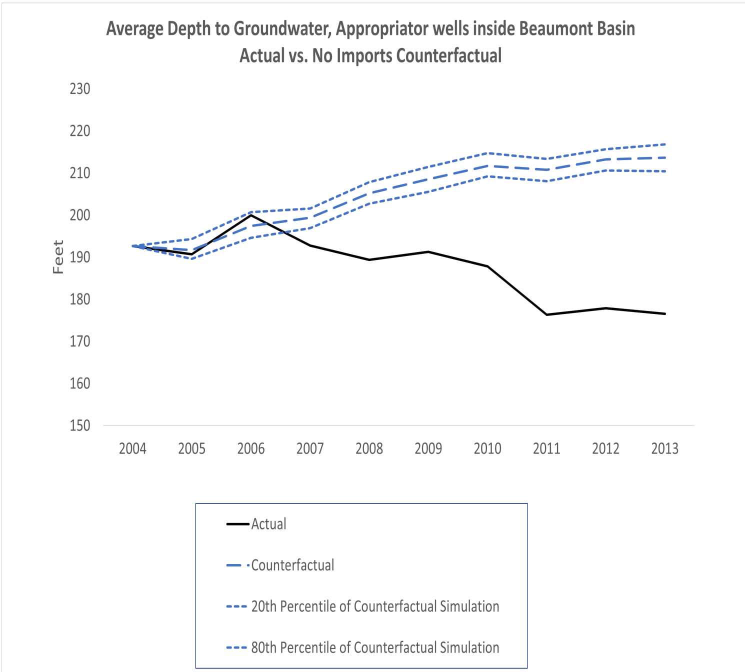



(b) Farmer Extraction outside Beaumont Basin

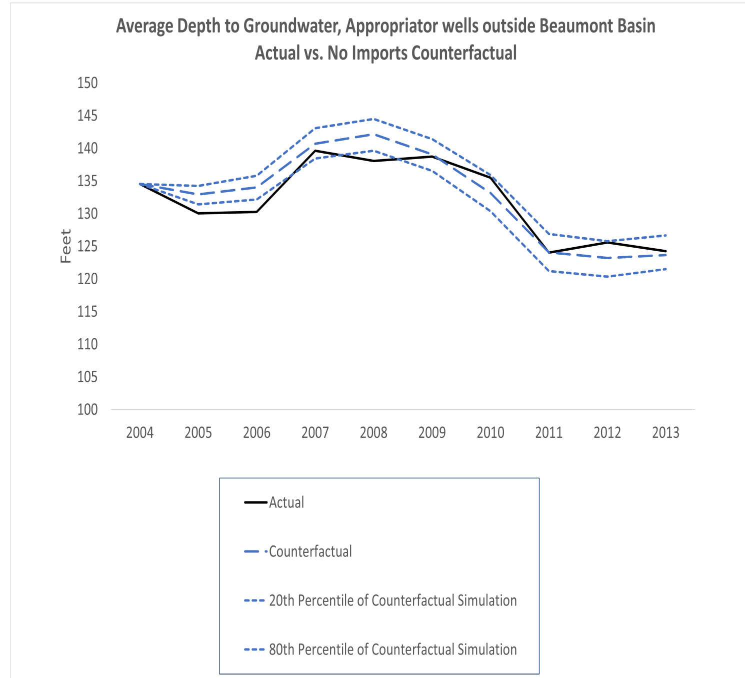



(c) Recreational User Extraction

Figure A.28: No Imports Counterfactual Comparison: Overlyer Behavior

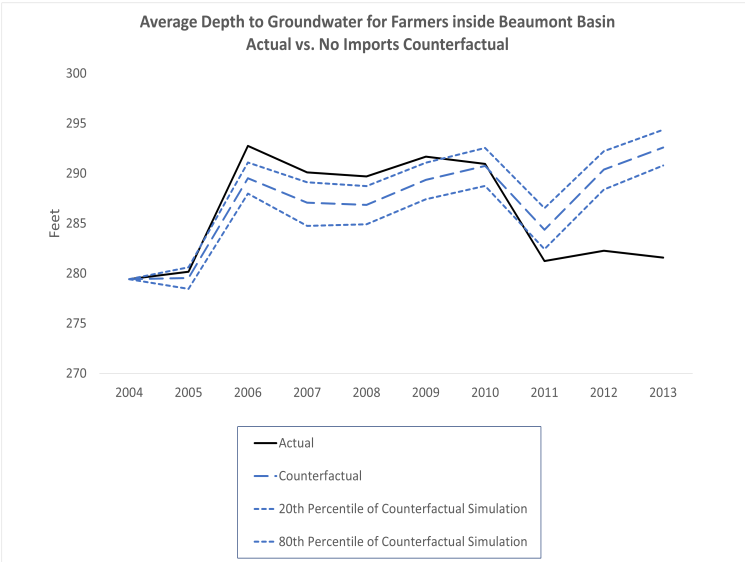



(a) Appropriator Depth to Groundwater inside Beaumont Basin

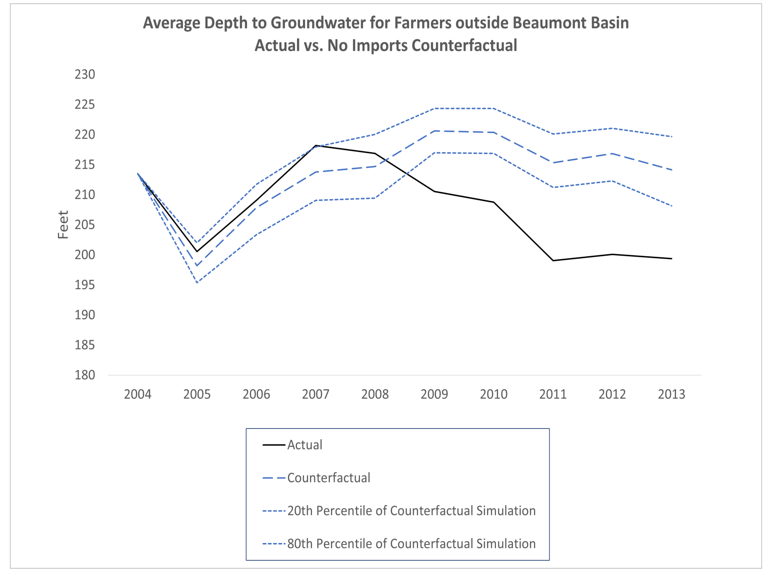



(b) Appropriator Depth to Groundwater outside Beaumont Basin

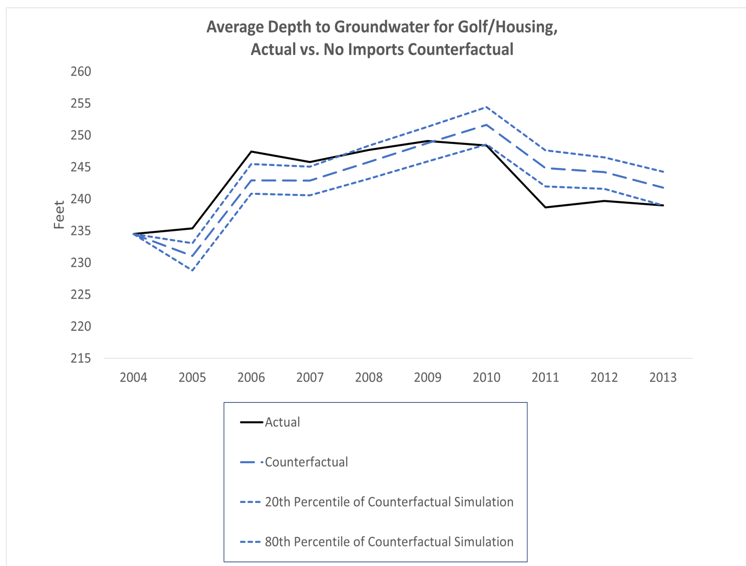
Figure A.29: No Imports Counterfactual Comparison: Appropriator Depth to Groundwater




(a) Farmer Depth
to Groundwater
inside Beaumont Basin

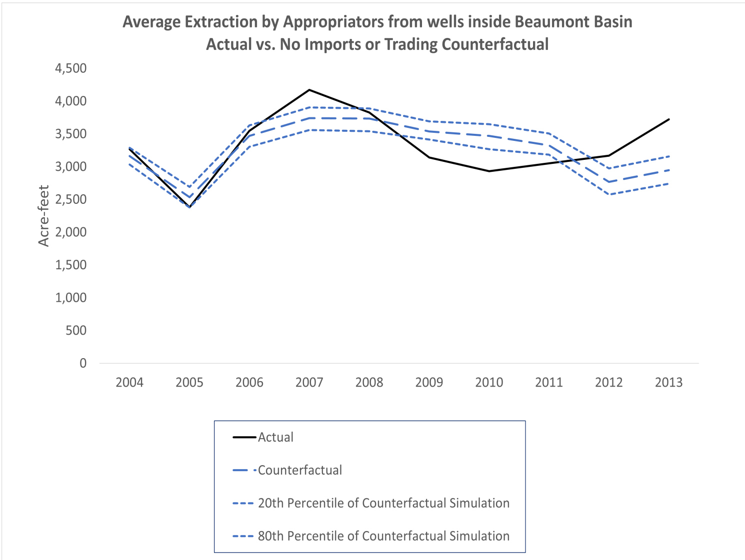



(b) Farmer Depth
to Groundwater
outside Beaumont Basin

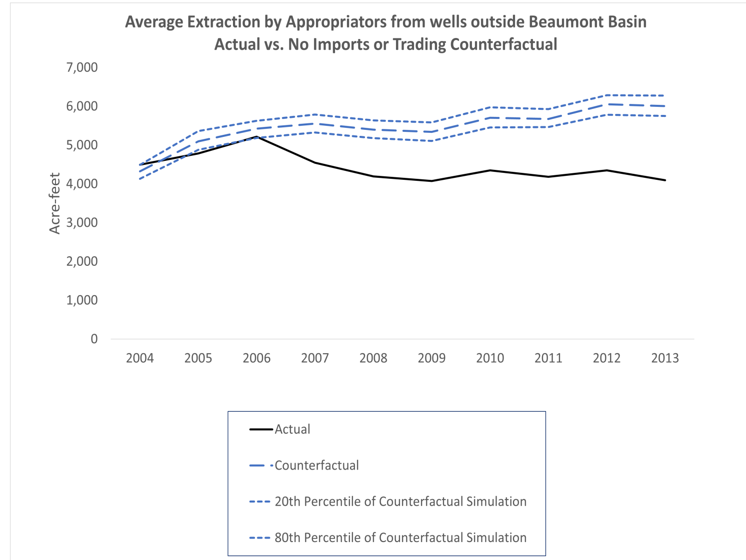



(c) Recreational User
Depth to Groundwater

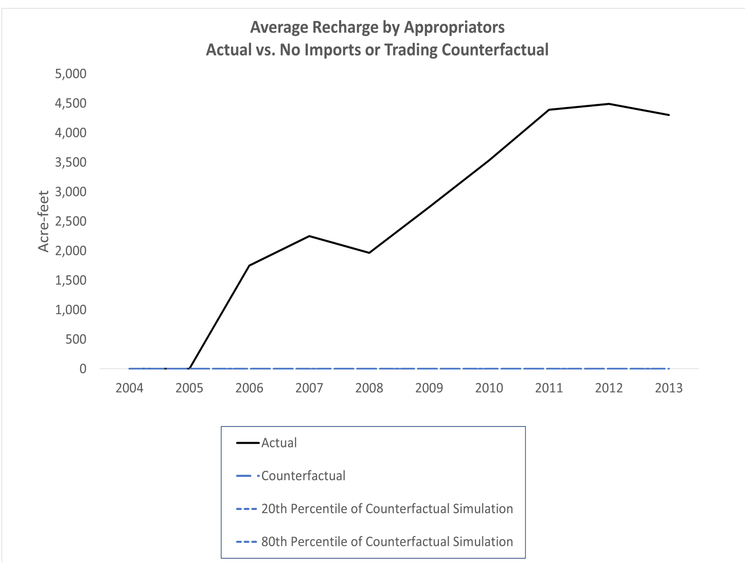
Figure A.30: No Imports Counterfactual Comparison: Overlyer Depth to Groundwater



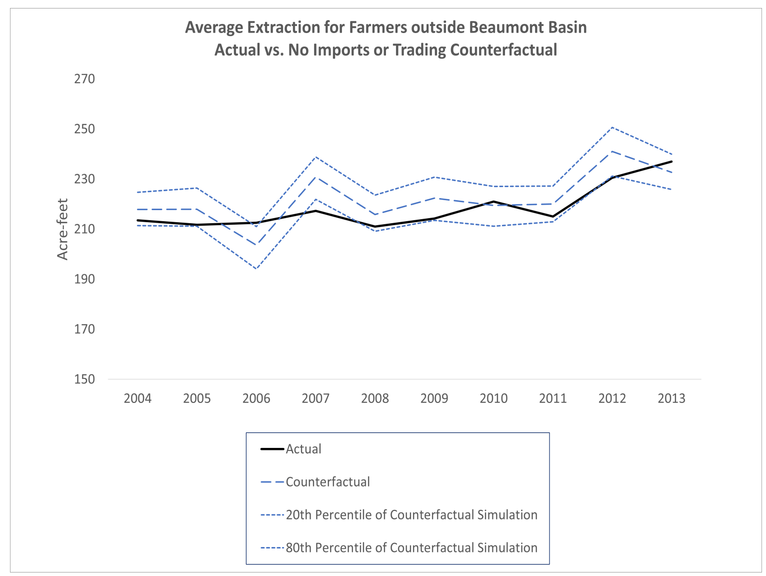

(a) Appropriator Extraction
inside Beaumont Basin




(b) Appropriator Extraction
outside Beaumont Basin

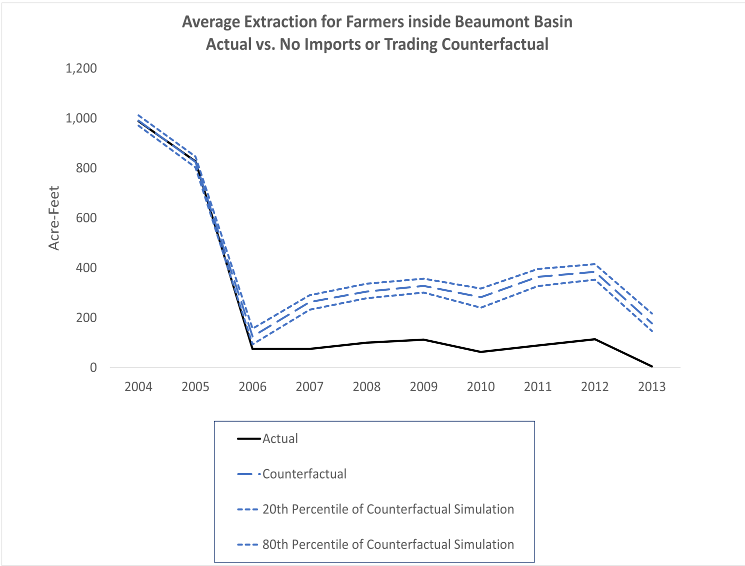



(c) Appropriator
Recharge

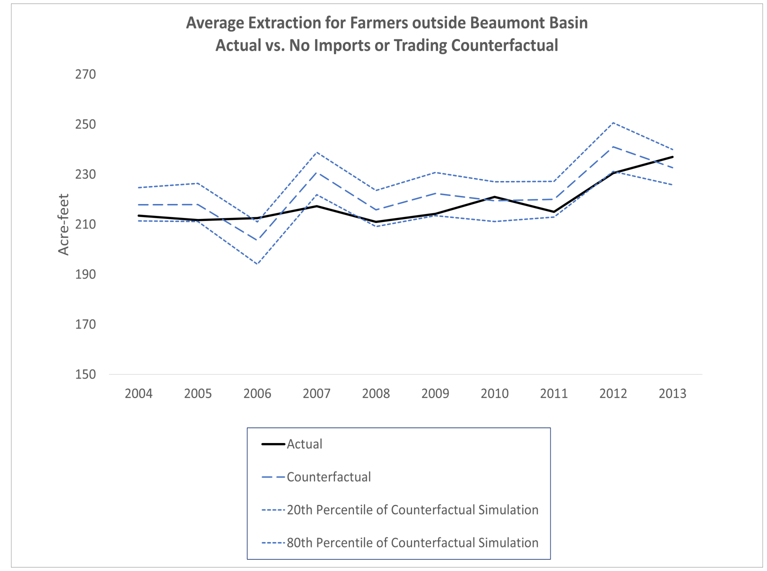



(d) Appropriator
Filtered Sales

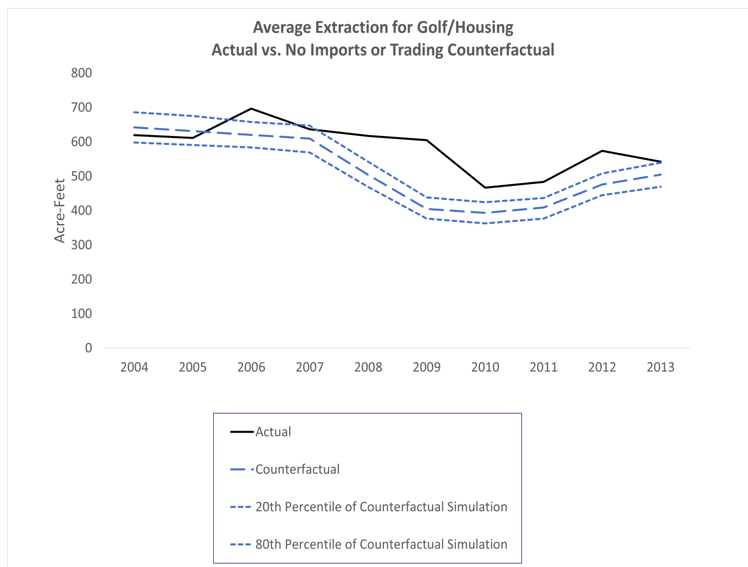
Figure A.31: No Imports or Trading Counterfactual Comparison: Appropriator Behavior




(a) Farmer Extraction inside Beaumont Basin

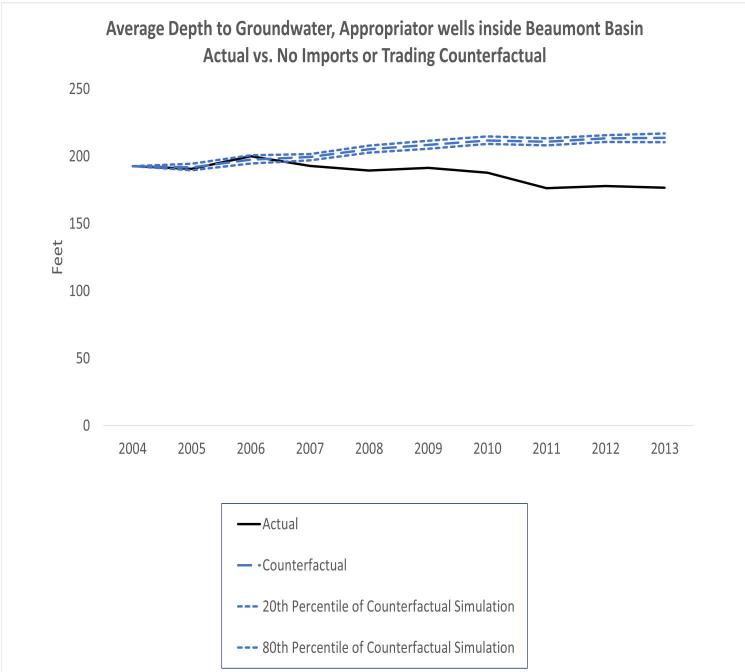



(b) Farmer Extraction outside Beaumont Basin

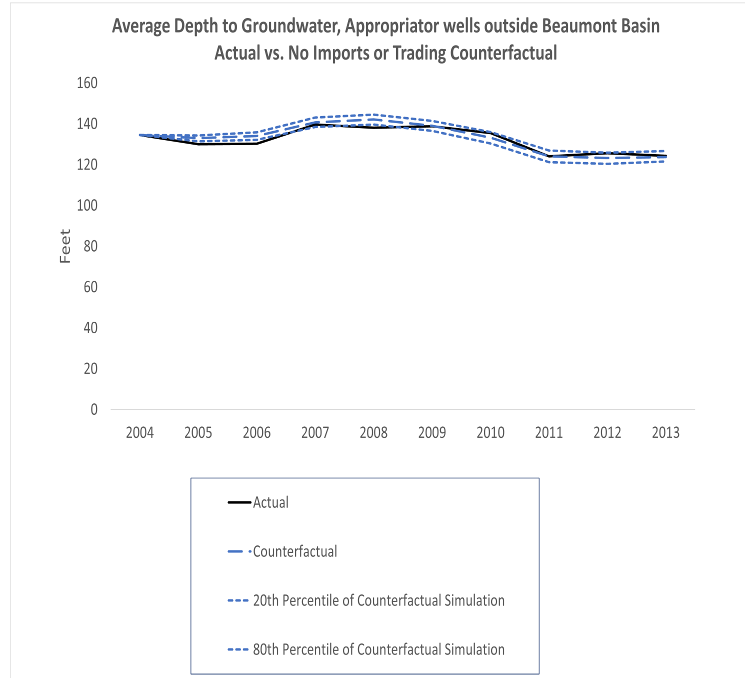



(c) Recreational User Extraction

Figure A.32: No Imports or Trading Counterfactual Comparison: Overlyer Behavior

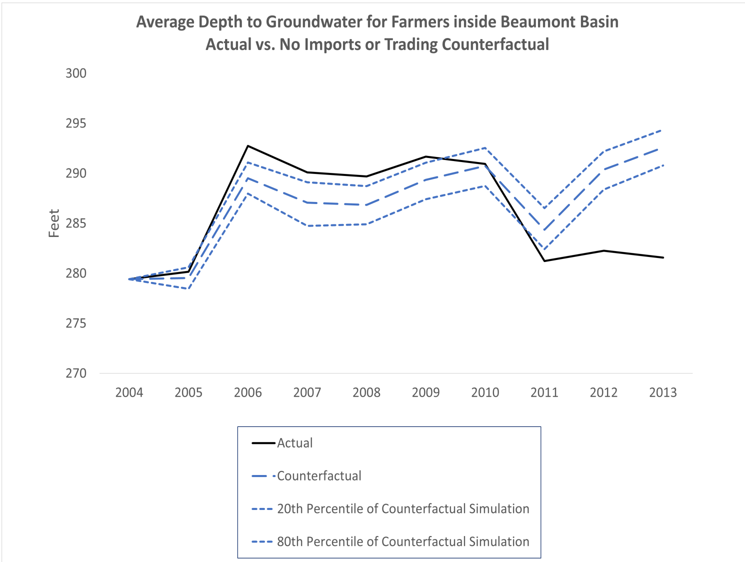



(a) Appropriator Depth to Groundwater inside Beaumont Basin

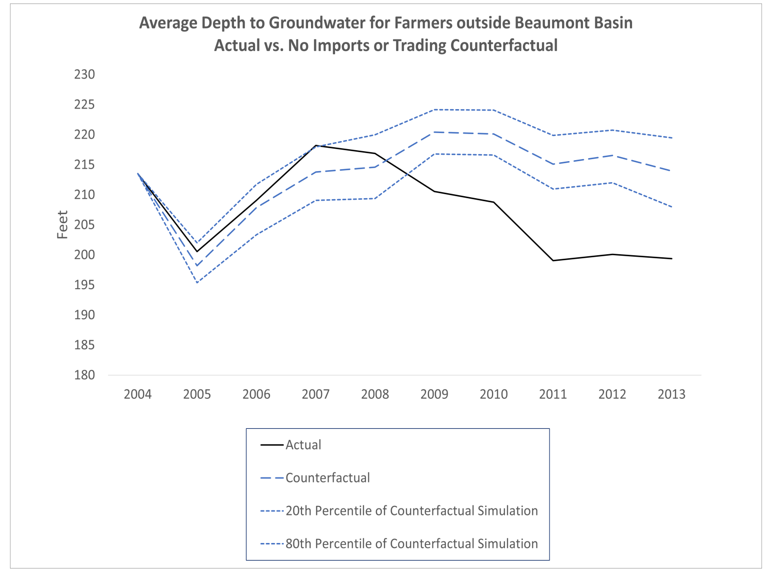



(b) Appropriator Depth to Groundwater outside Beaumont Basin

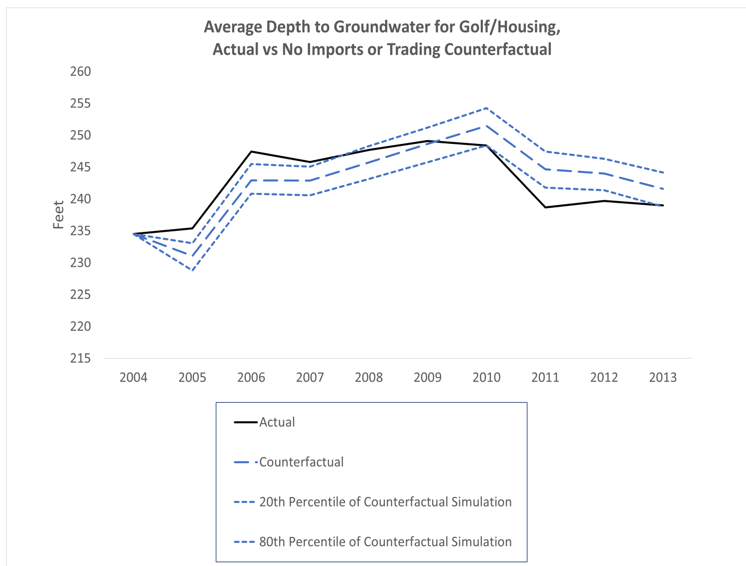
Figure A.33: No Imports or Trading Counterfactual Comparison: Appropriator Depth to Groundwater




(a) Farmer Depth to Groundwater inside Beaumont Basin

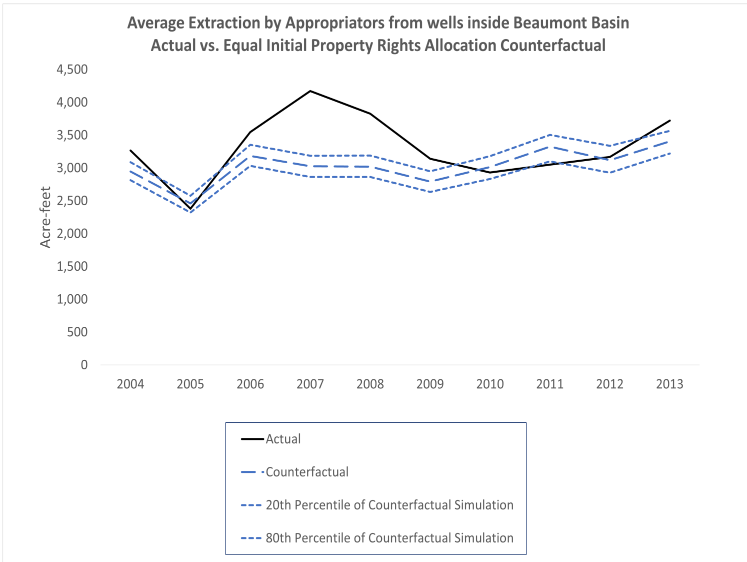



(b) Farmer Depth to Groundwater outside Beaumont Basin

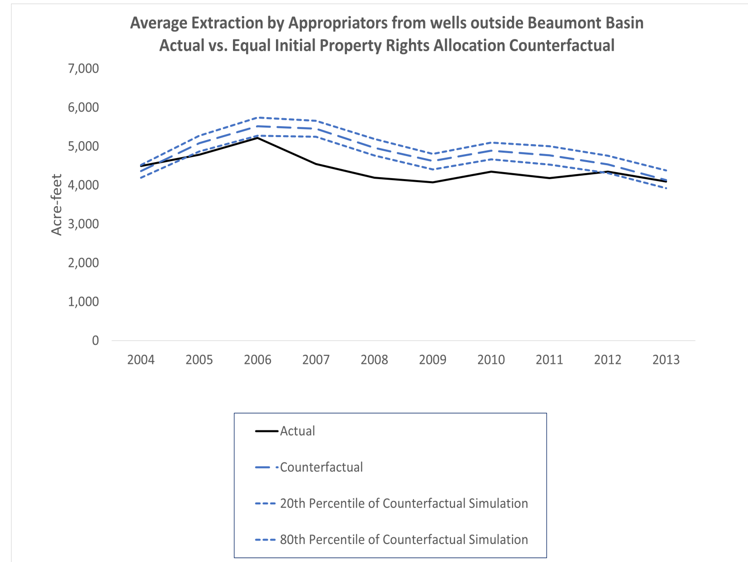



(c) Recreational User Depth to Groundwater

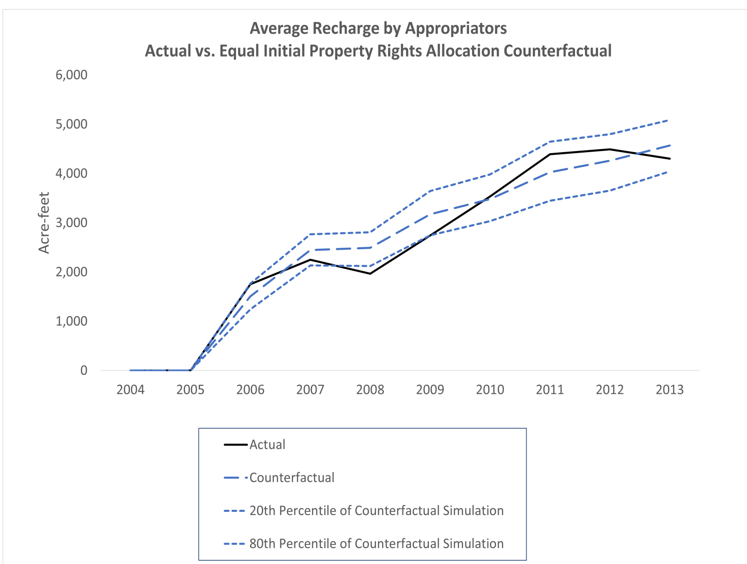
Figure A.34: No Imports or Trading Counterfactual Comparison: Overlyer Depth to Groundwater



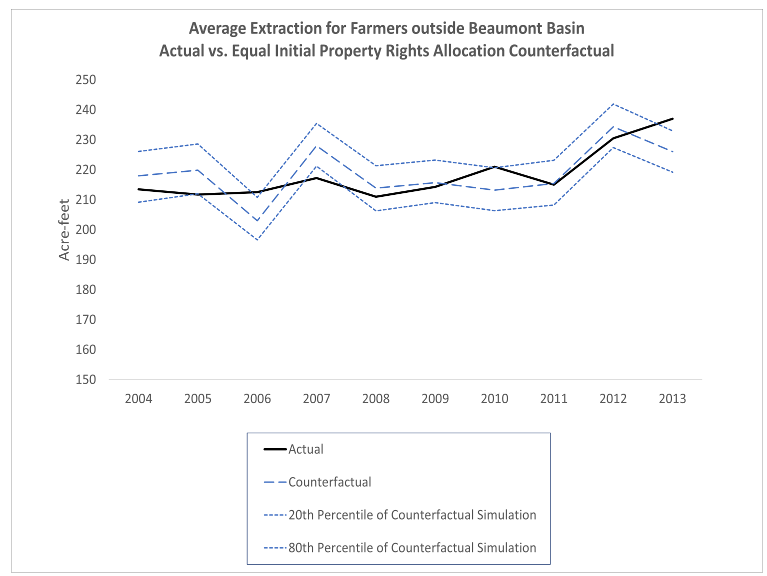

(a) Appropriator Extraction inside Beaumont Basin




(b) Appropriator Extraction outside Beaumont Basin

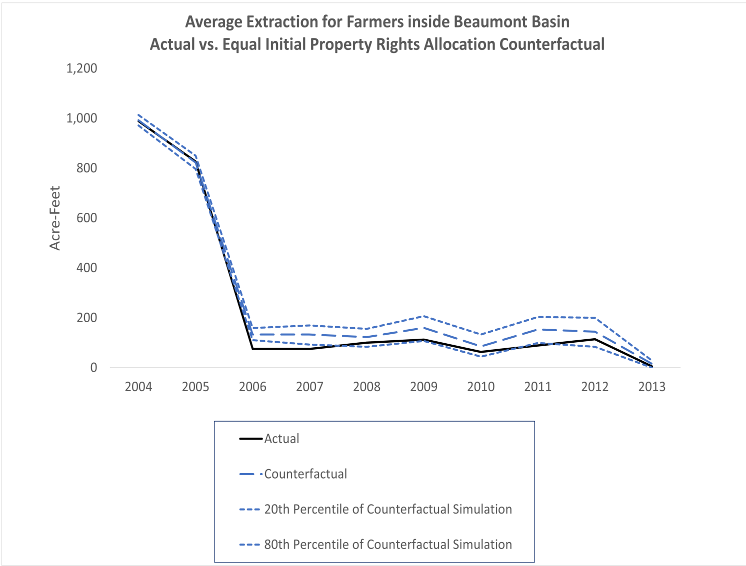



(c) Appropriator Recharge

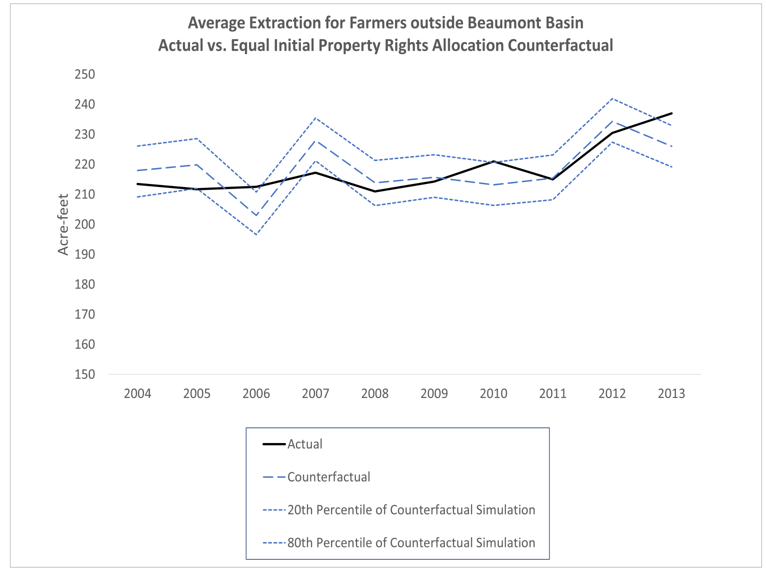



(d) Appropriator Filtered Sales

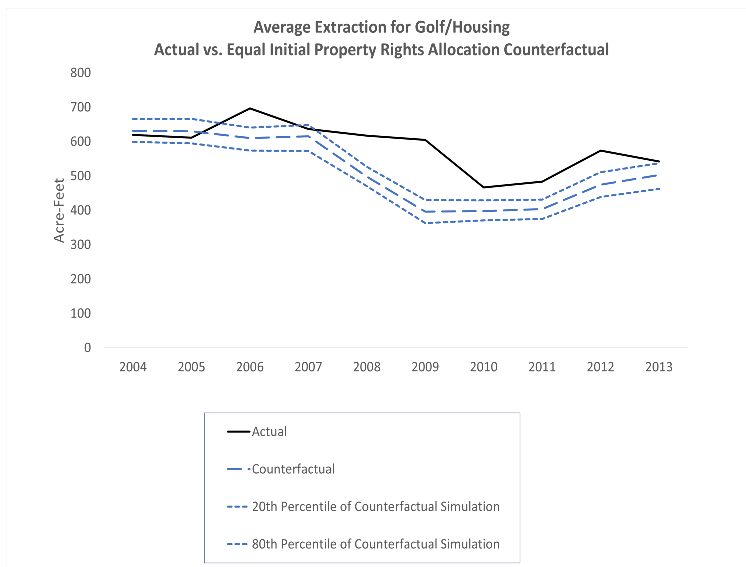
Figure A.35: Equal Initial Property Rights Allocation Counterfactual Comparison: Appropriator Behavior




(a) Farmer Extraction inside Beaumont Basin

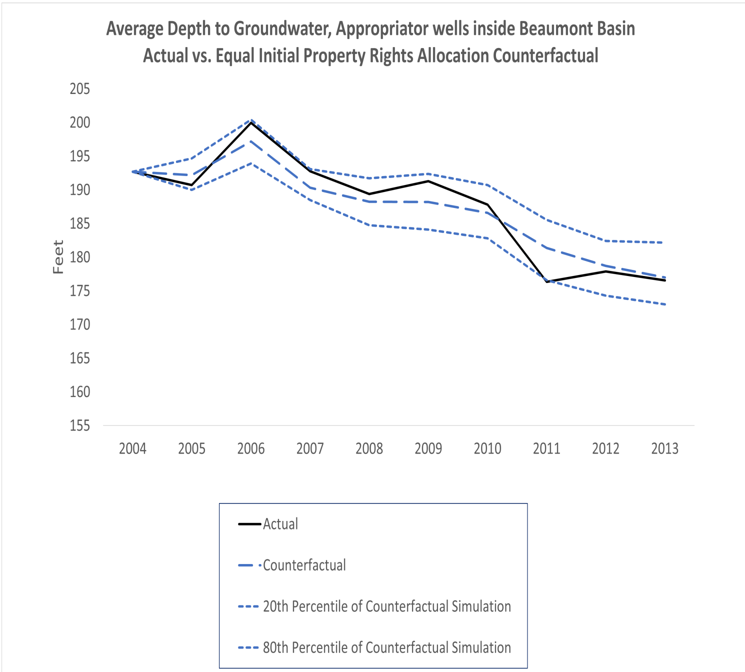



(b) Farmer Extraction outside Beaumont Basin

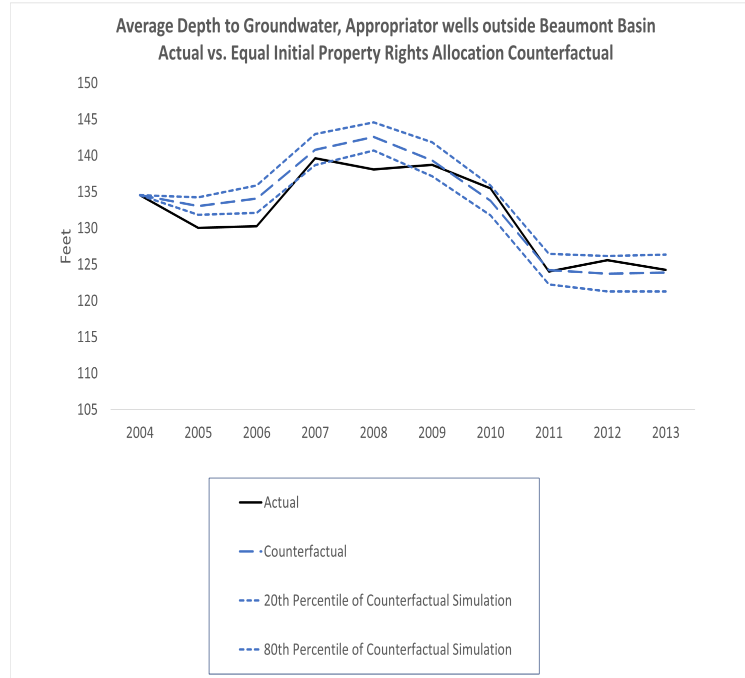



(c) Recreational User Extraction

Figure A.36: Equal Initial Property Rights Allocation Counterfactual Comparison: Overlyer Behavior

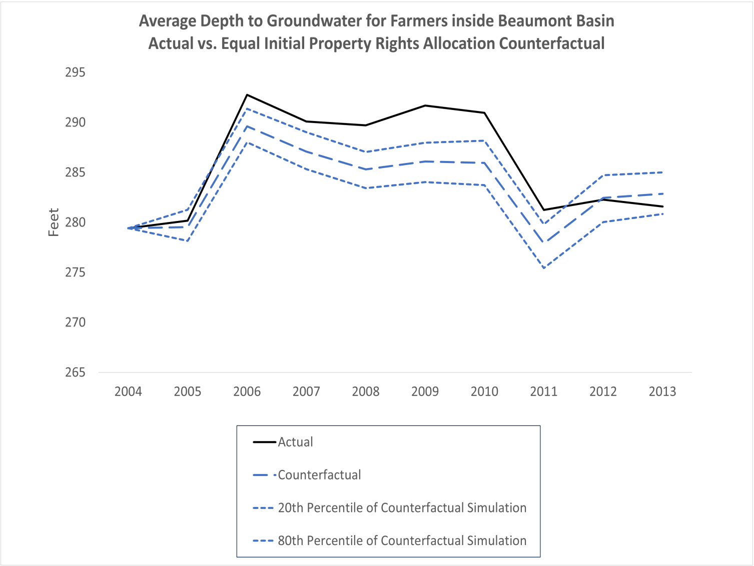



(a) Appropriator Depth to Groundwater inside Beaumont Basin

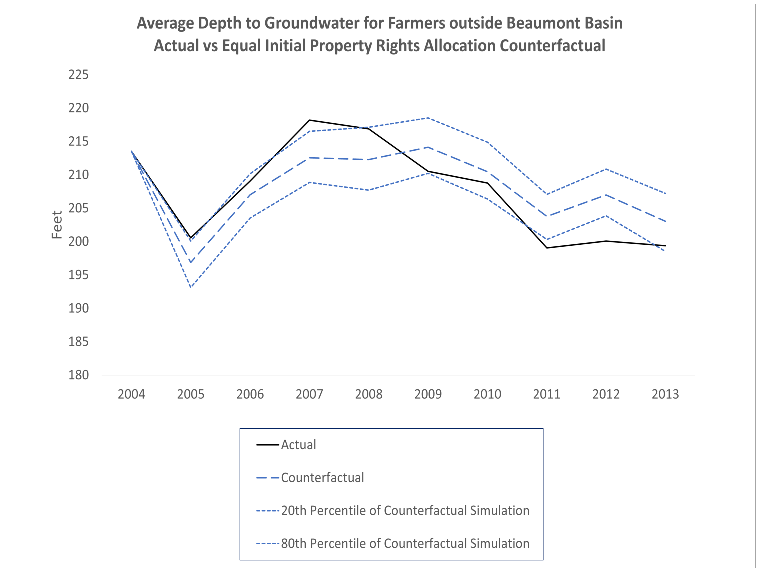



(b) Appropriator Depth to Groundwater outside Beaumont Basin

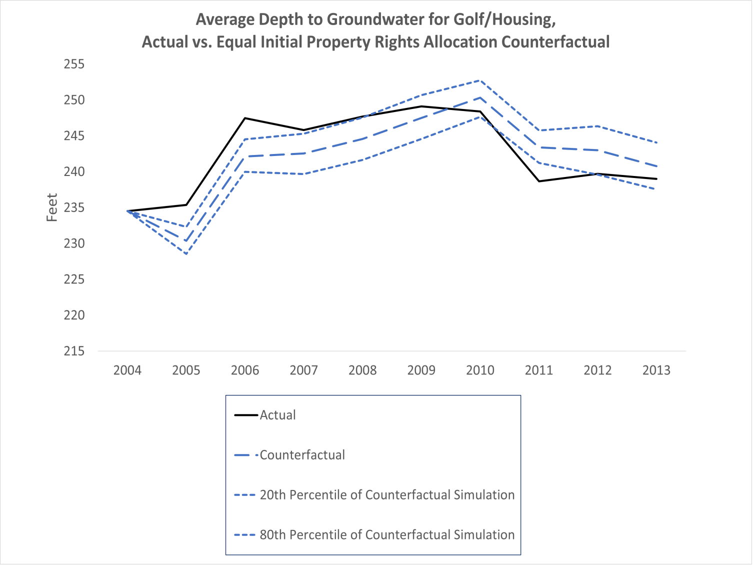
Figure A.37: Equal Initial Property Rights Allocation Counterfactual Comparison: Appropriator Depth to Groundwater




(a) Farmer Depth to Groundwater inside Beaumont Basin

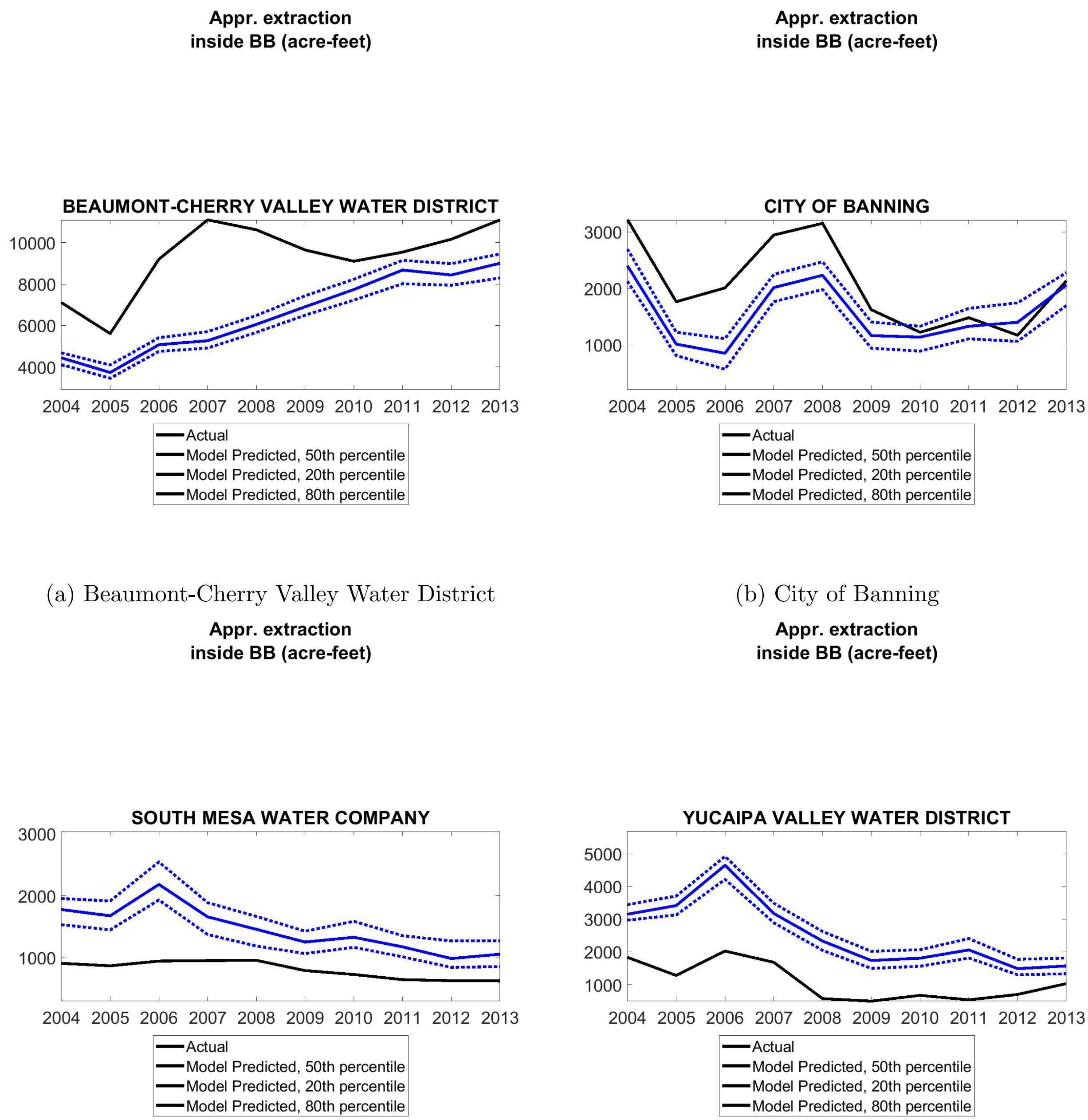



(b) Farmer Depth to Groundwater outside Beaumont Basin




(c) Recreational User Depth to Groundwater

Figure A.38: Equal Initial Property Rights Allocation Counterfactual Comparison: Overlyer Depth to Groundwater



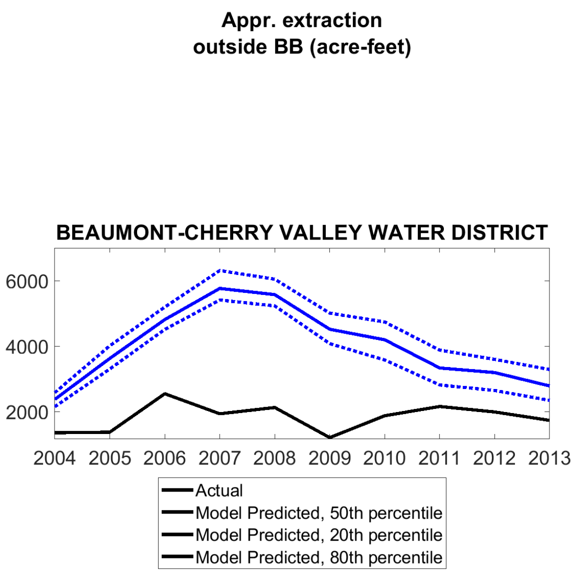

(a) Beaumont-Cherry Valley Water District

(b) City of Banning

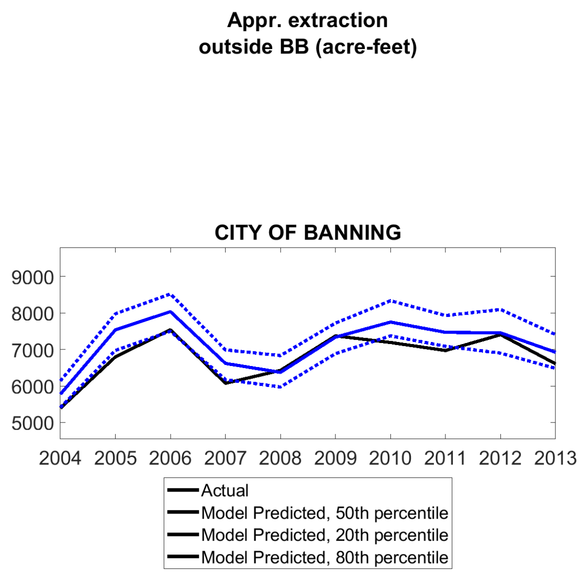
(c) South Mesa Water Company

(d) Yucaipa Valley Water District

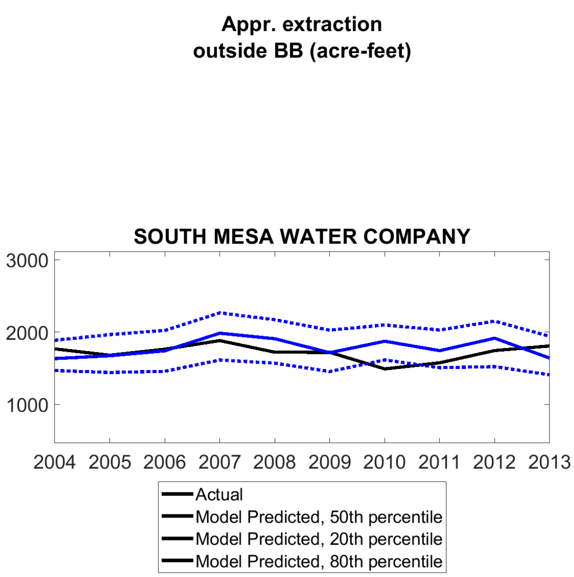
Figure A.39: Equal Initial Property Rights Allocation Counterfactual Comparison: Appropriator Extraction in Beaumont Basin



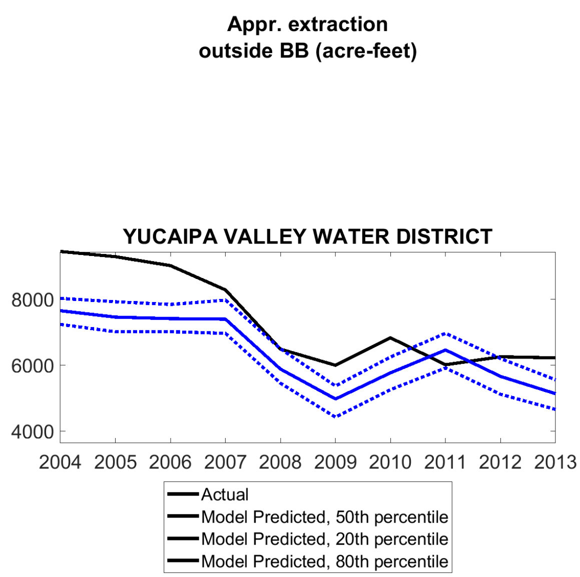

(a) Beaumont-Cherry Valley Water District




(b) City of Banning

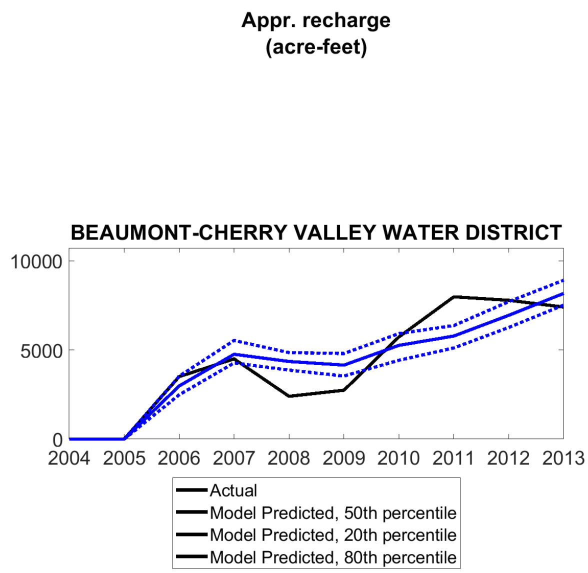



(c) South Mesa Water Company

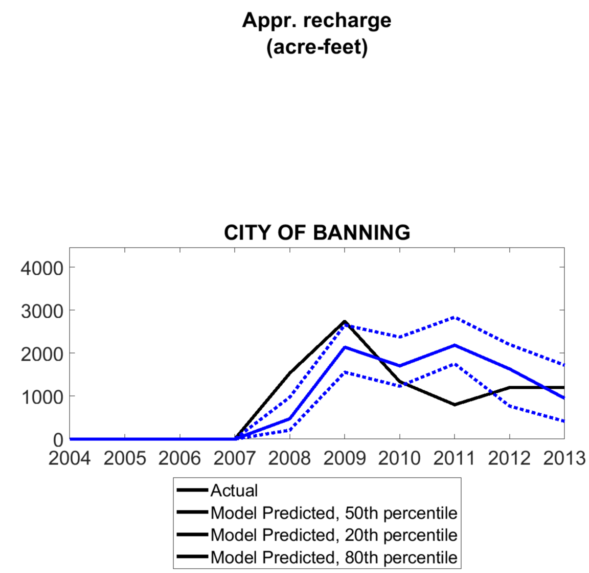



(d) Yucaipa Valley Water District

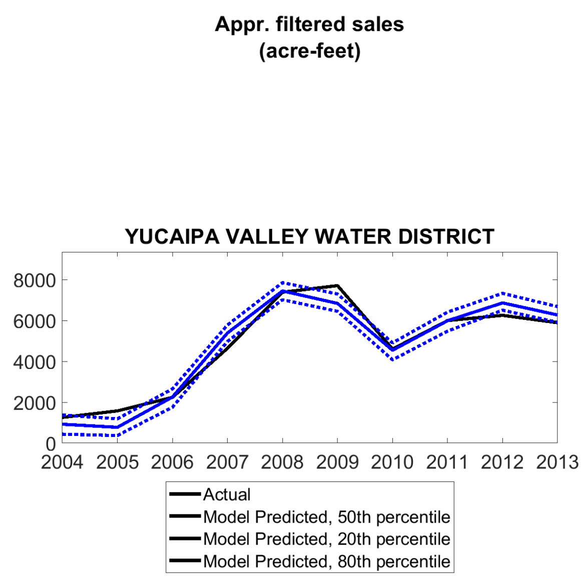
Figure A.40: Equal Initial Property Rights Allocation Counterfactual Comparison: Appropriator Extraction outside Beaumont Basin




(a) Beaumont-Cherry Valley Water District

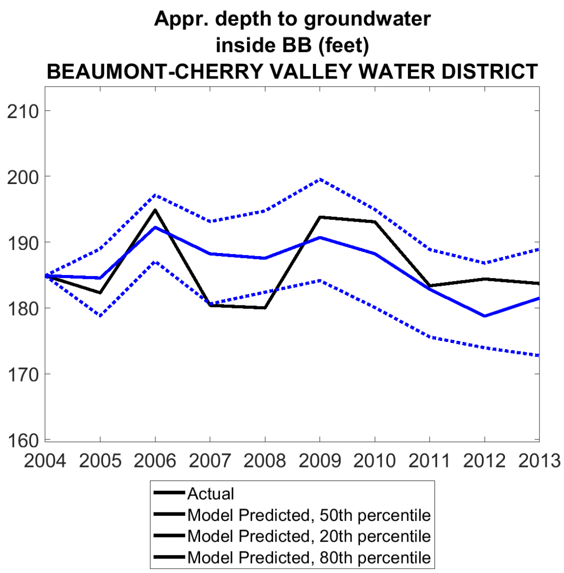



(b) City of Banning

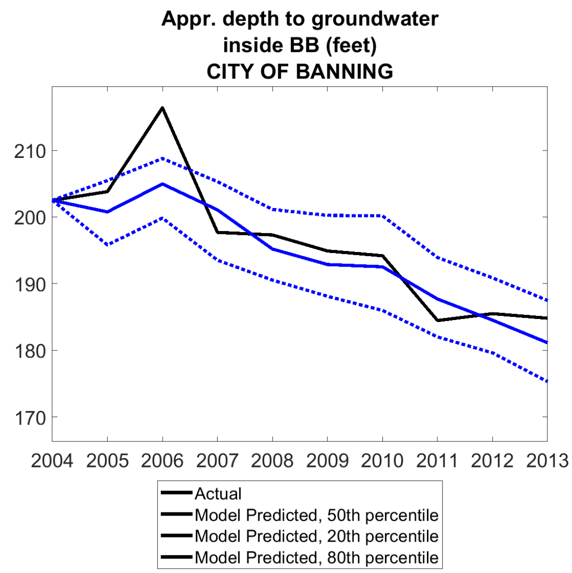



(c) Yucaipa Valley Water District

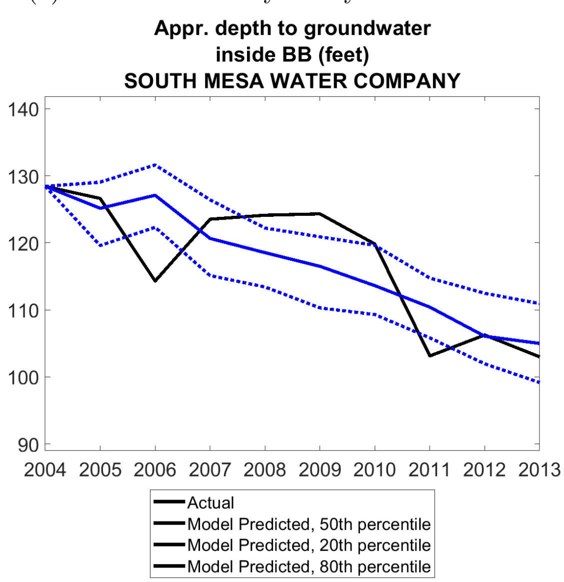
Figure A.41: Equal Initial Property Rights Allocation Counterfactual Comparison: Appropriator Water Imports



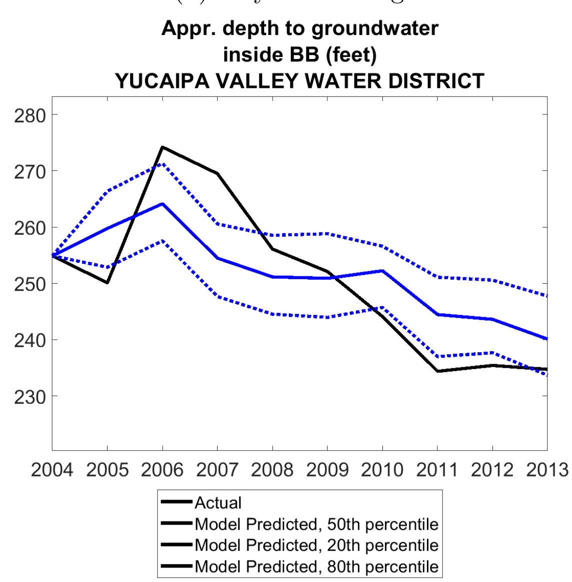

(a) Beaumont-Cherry Valley Water District




(b) City of Banning

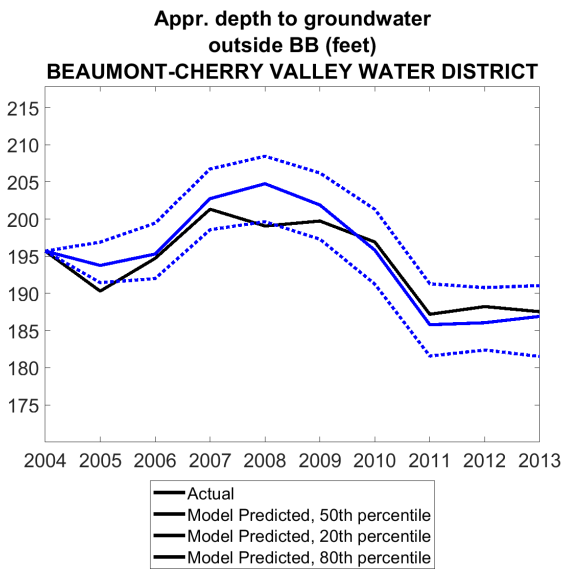



(c) South Mesa Water Company

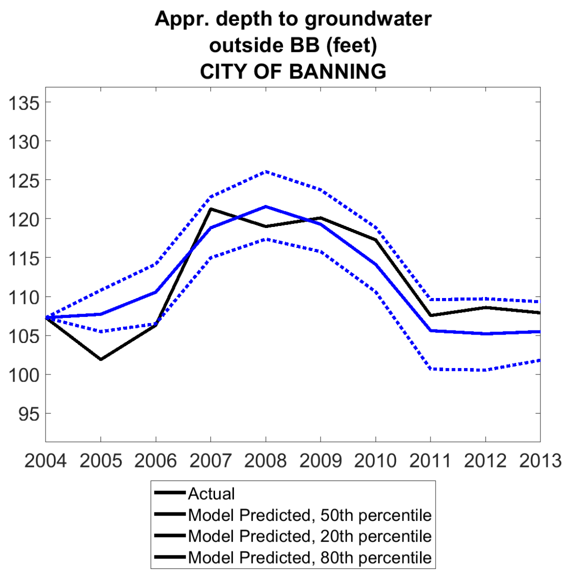



(d) Yucaipa Valley Water District

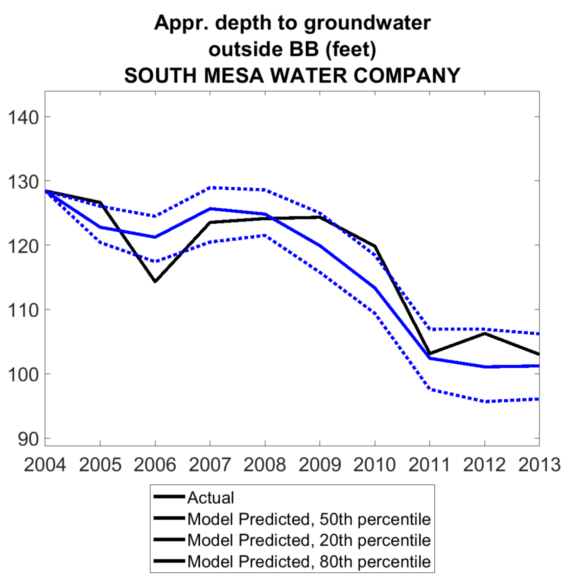
Figure A.42: Equal Initial Property Rights Allocation Counterfactual Comparison: Appropriator Depth to Groundwater in Beaumont Basin



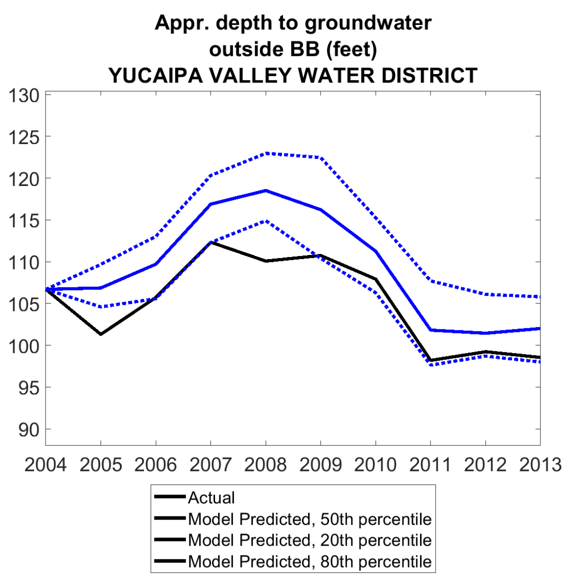

(a) Beaumont-Cherry Valley Water District




(b) City of Banning

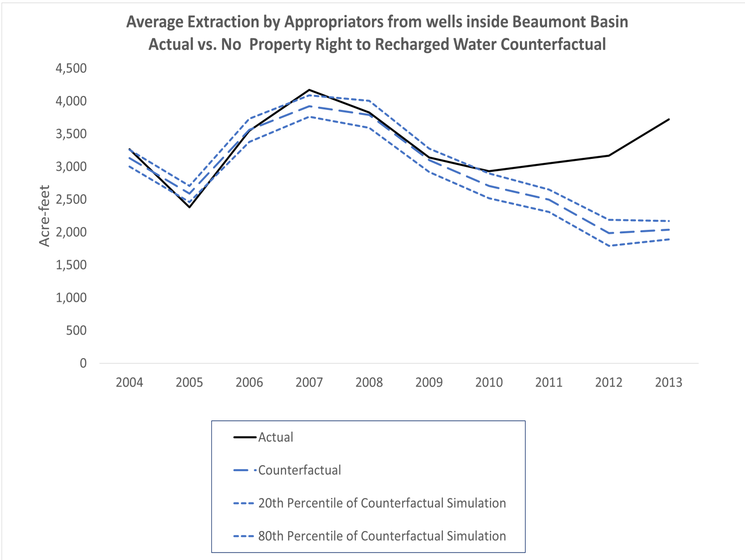



(c) South Mesa Water Company

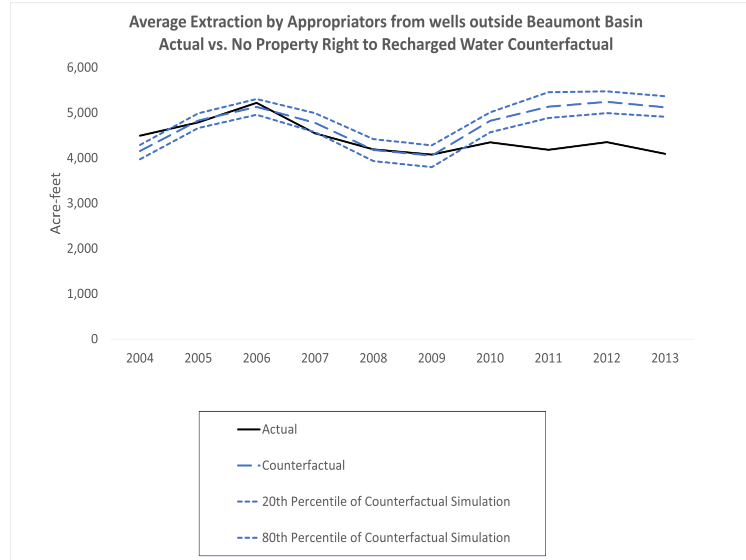



(d) Yucaipa Valley Water District

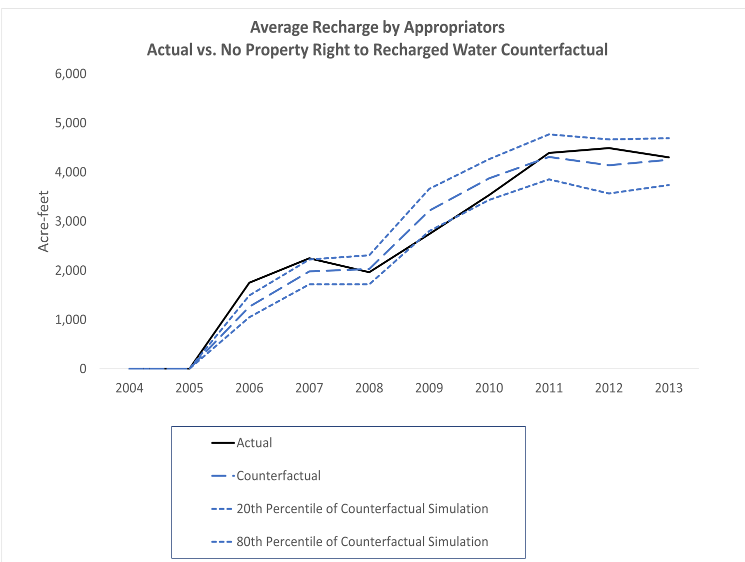
Figure A.43: Equal Initial Property Rights Allocation Counterfactual Comparison: Appropriator Depth to Groundwater outside Beaumont Basin



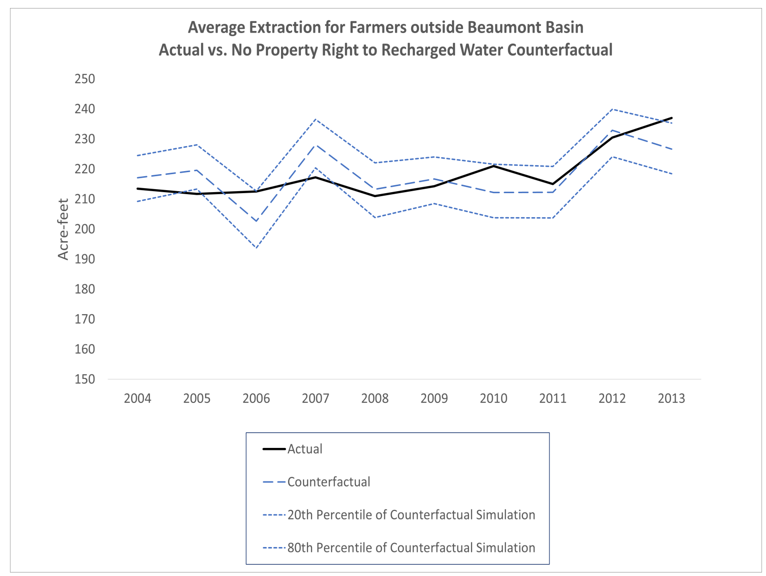

(a) Appropriator Extraction
inside Beaumont Basin




(b) Appropriator Extraction
outside Beaumont Basin

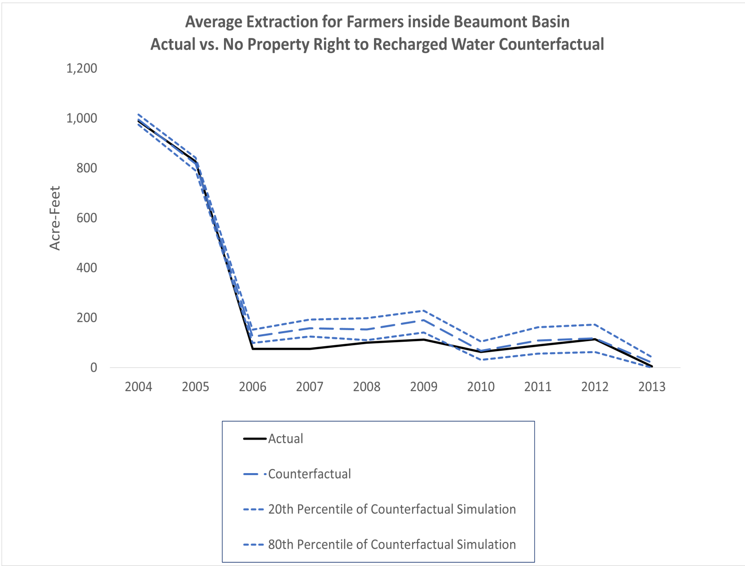



(c) Appropriator
Recharge

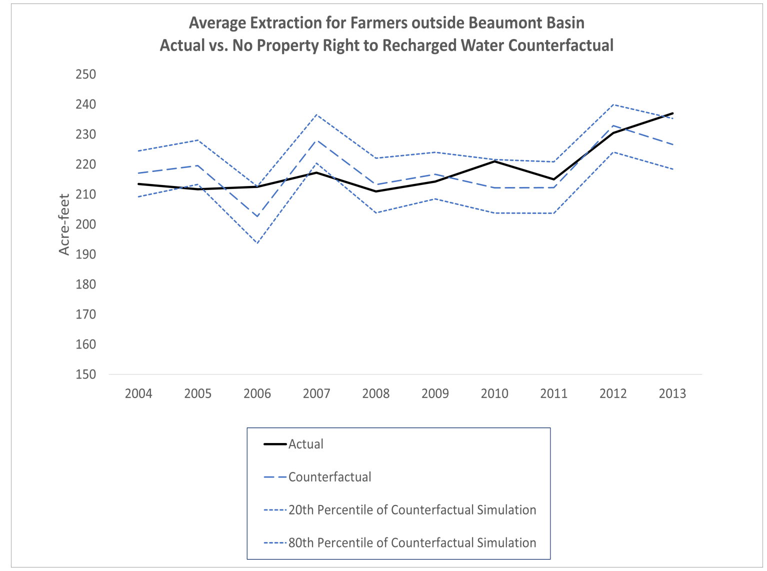



(d) Appropriator
Filtered Sales

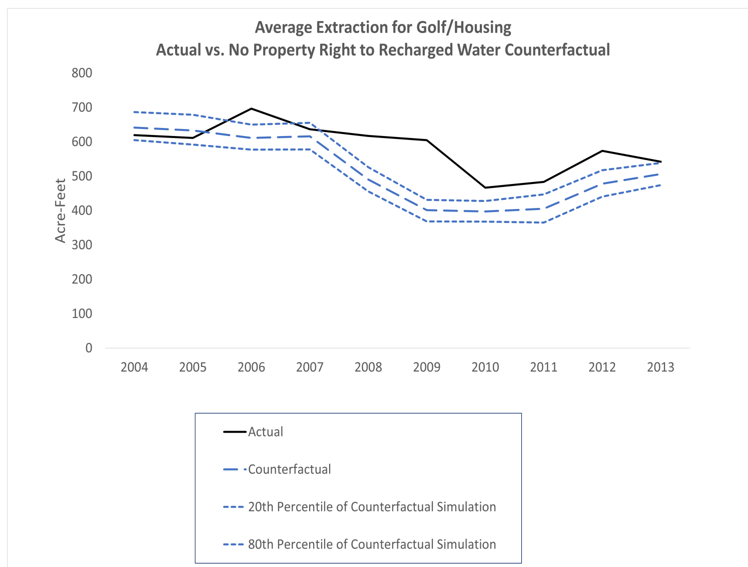
Figure A.44: No Property Right to Recharged Water Counterfactual Comparison: Appropriator Behavior




(a) Farmer Extraction inside Beaumont Basin

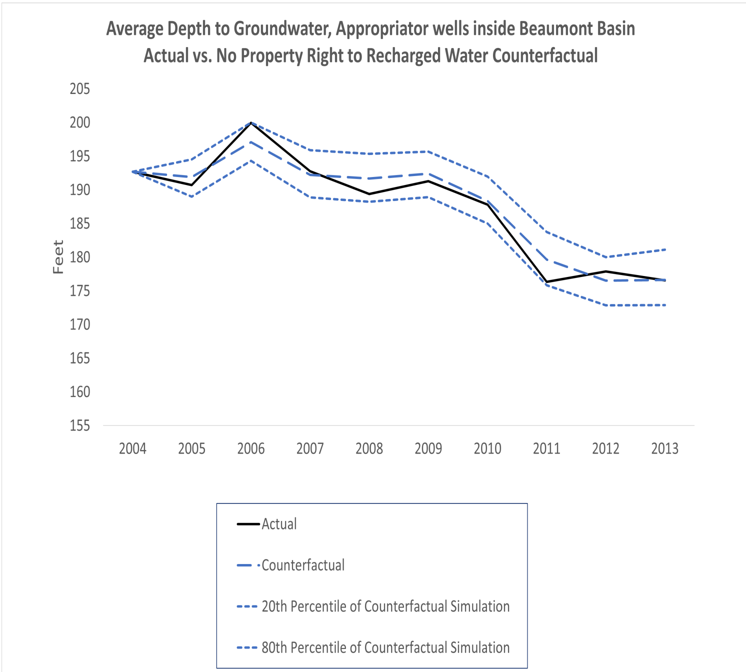



(b) Farmer Extraction outside Beaumont Basin

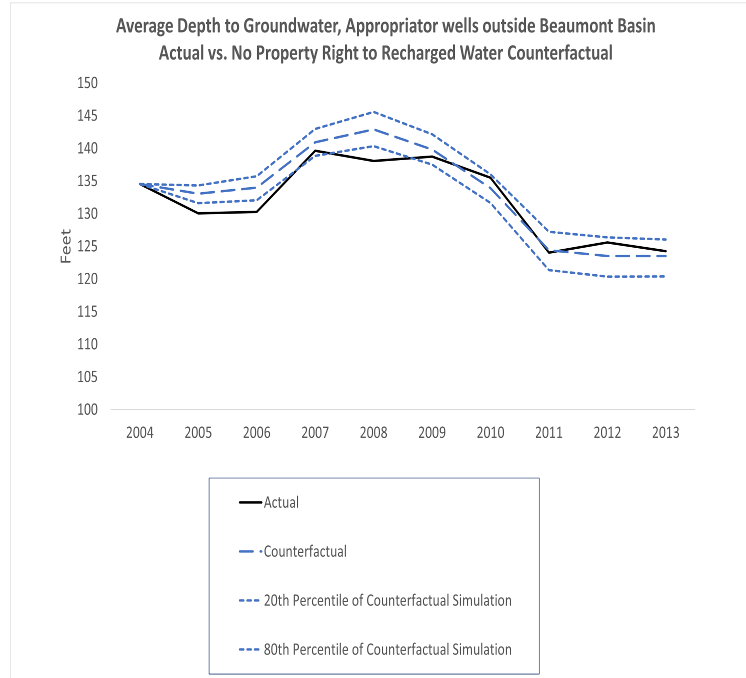



(c) Recreational User Extraction

Figure A.45: No Property Right to Recharged Water Counterfactual Comparison: Overlyer Behavior

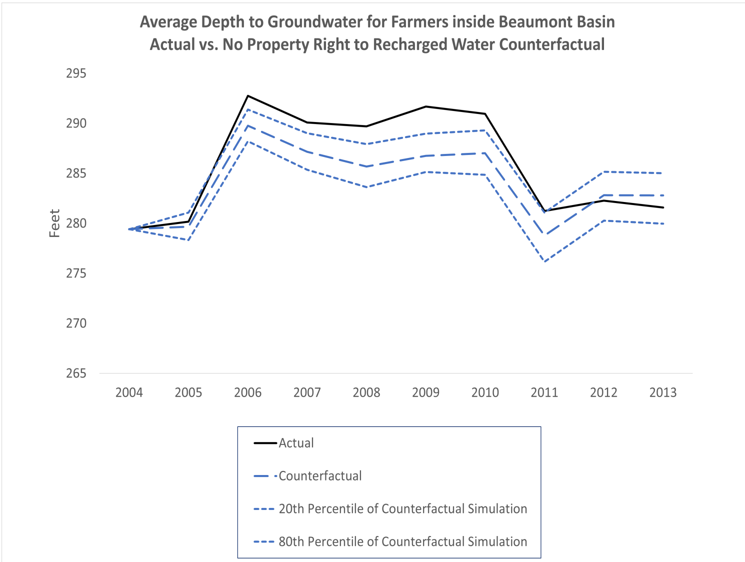



(a) Appropriator Depth to Groundwater inside Beaumont Basin

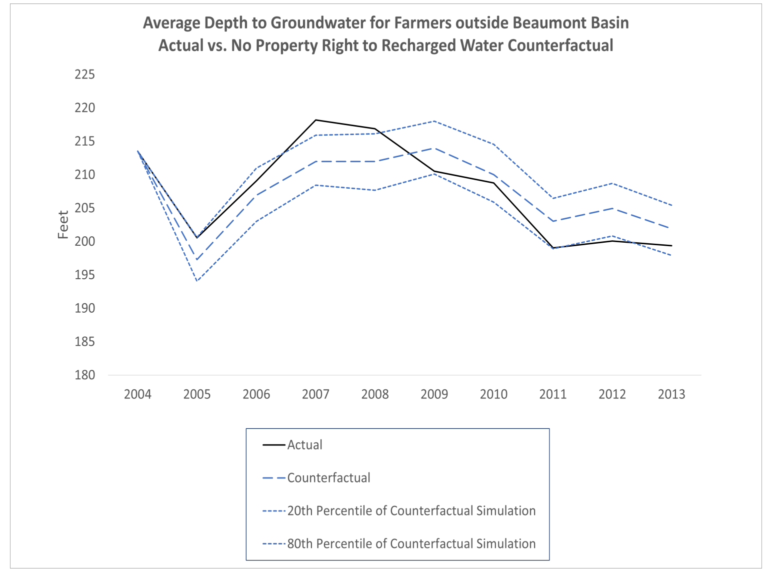



(b) Appropriator Depth to Groundwater outside Beaumont Basin

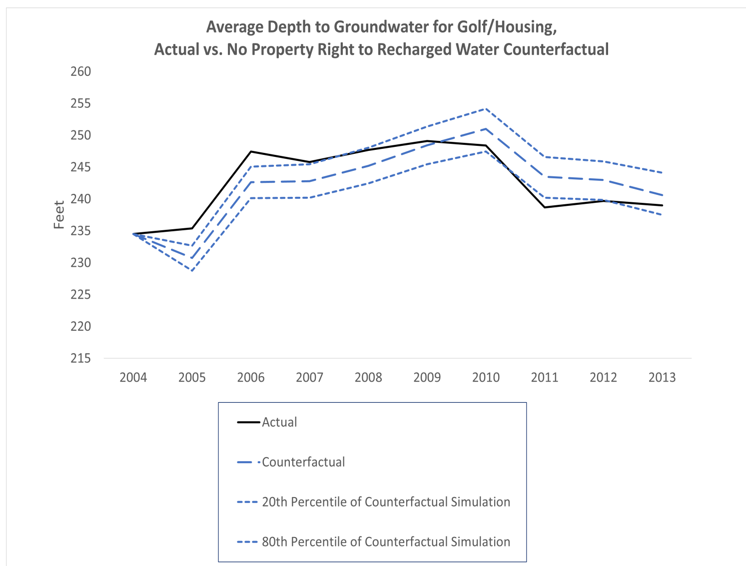
Figure A.46: No Property Right to Recharged Water Counterfactual Comparison: Appropriator Depth to Groundwater




(a) Farmer Depth to Groundwater inside Beaumont Basin

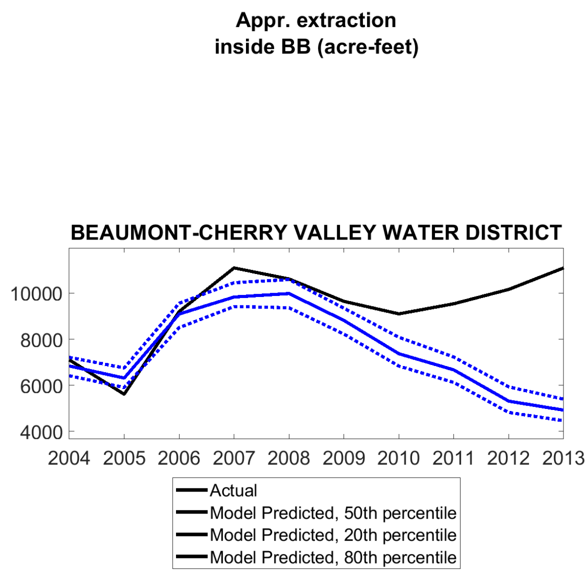



(b) Farmer Depth to Groundwater outside Beaumont Basin

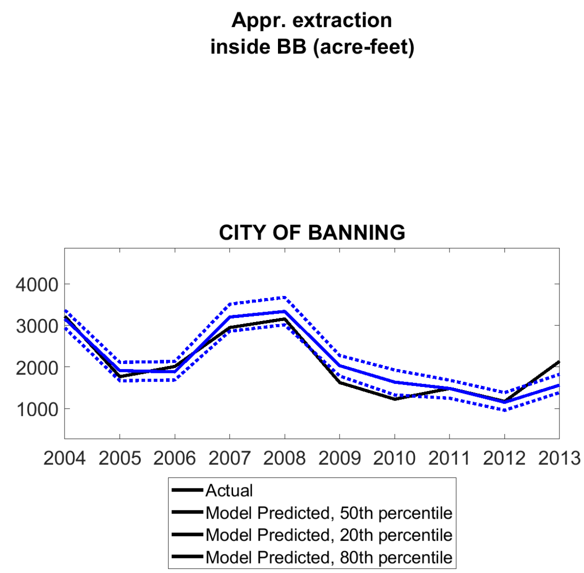



(c) Recreational User Depth to Groundwater

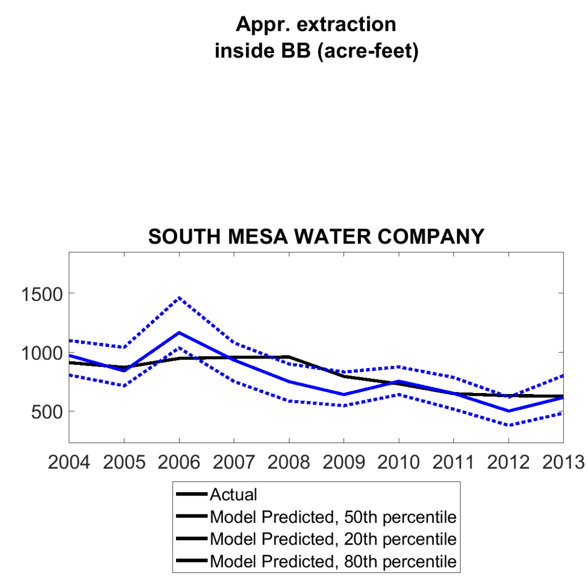
Figure A.47: No Property Right to Recharged Water Counterfactual Comparison: Overlyer Depth to Groundwater



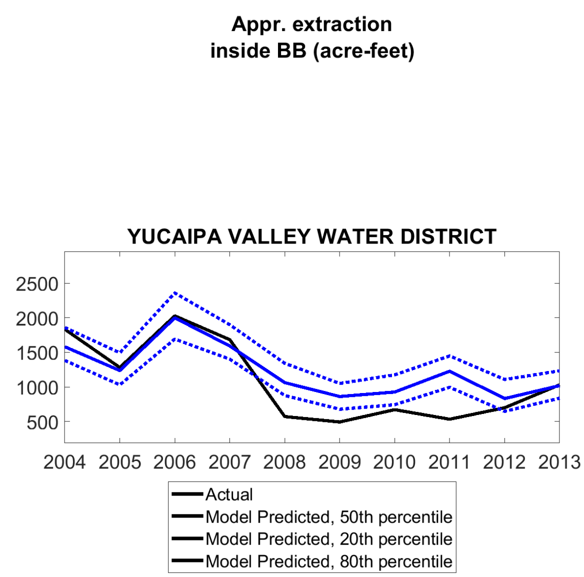

(a) Beaumont-Cherry Valley Water District




(b) City of Banning

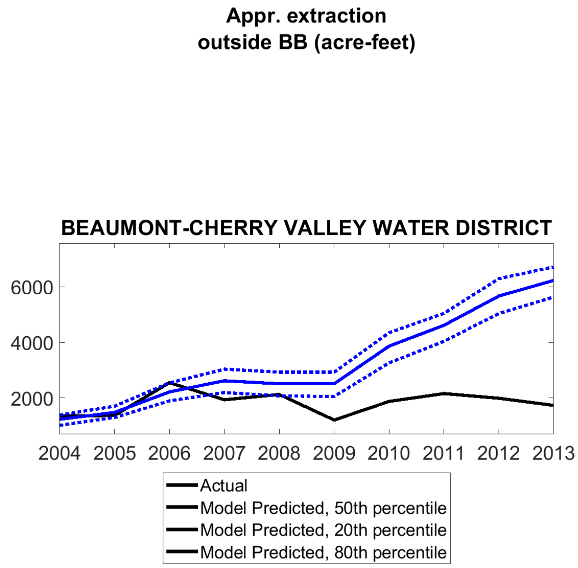



(c) South Mesa Water Company

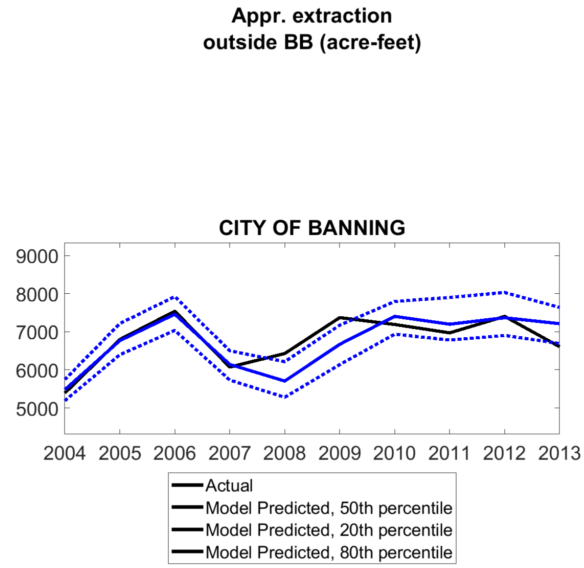



(d) Yucaipa Valley Water District

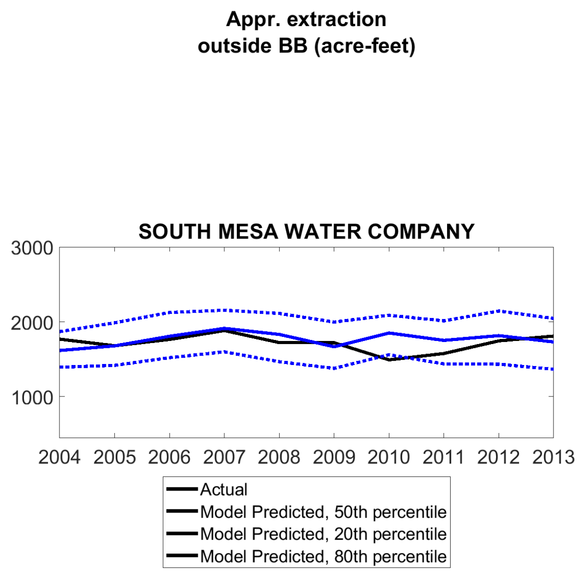
Figure A.48: No Property Right to Recharged Water Counterfactual Comparison: Appropriator Extraction in Beaumont Basin



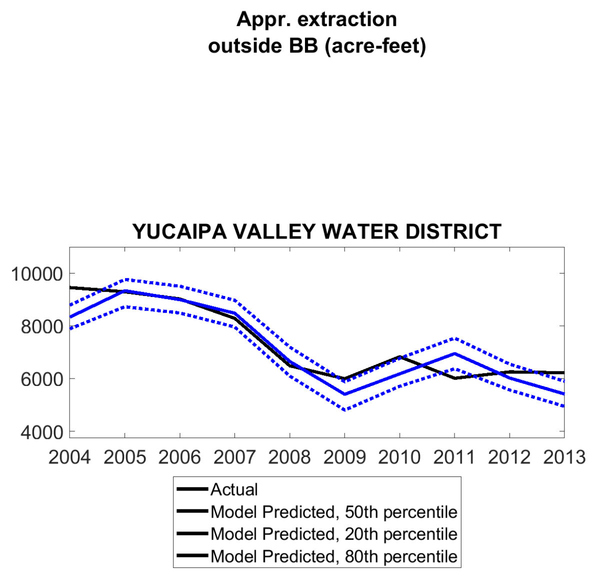

(a) Beaumont-Cherry Valley Water District




(b) City of Banning

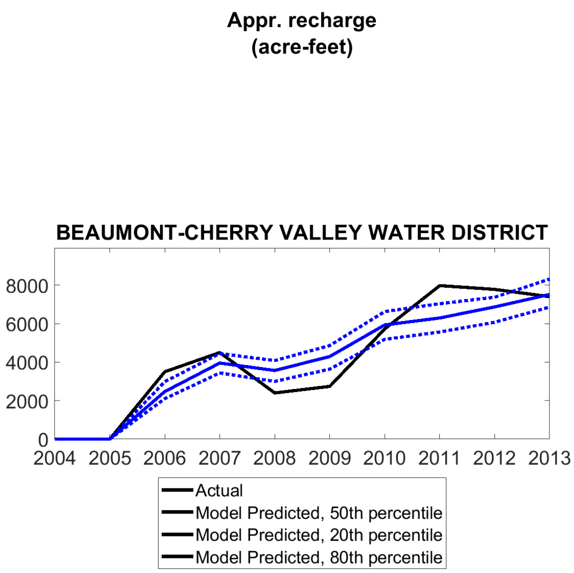



(c) South Mesa Water Company

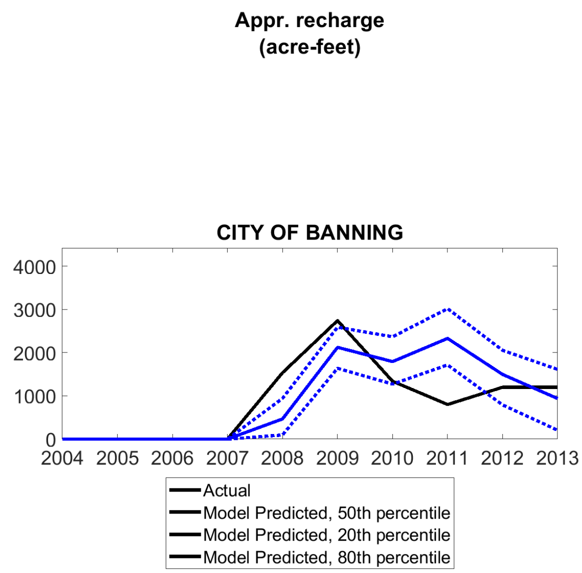



(d) Yucaipa Valley Water District

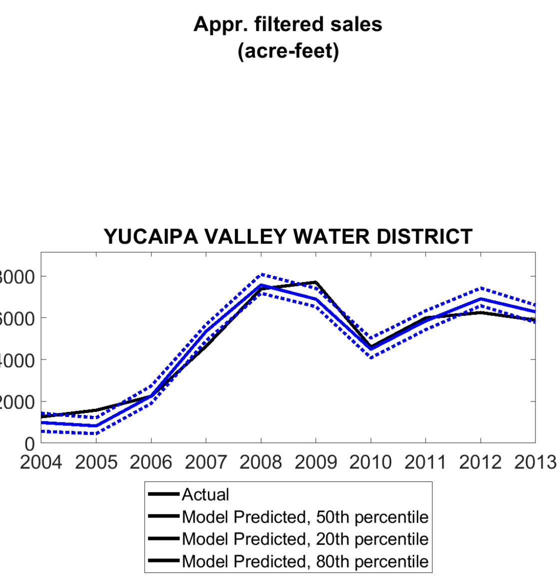
Figure A.49: No Property Right to Recharged Water Counterfactual Comparison: Appropriator Extraction outside Beaumont Basin




(a) Beaumont-Cherry Valley Water District

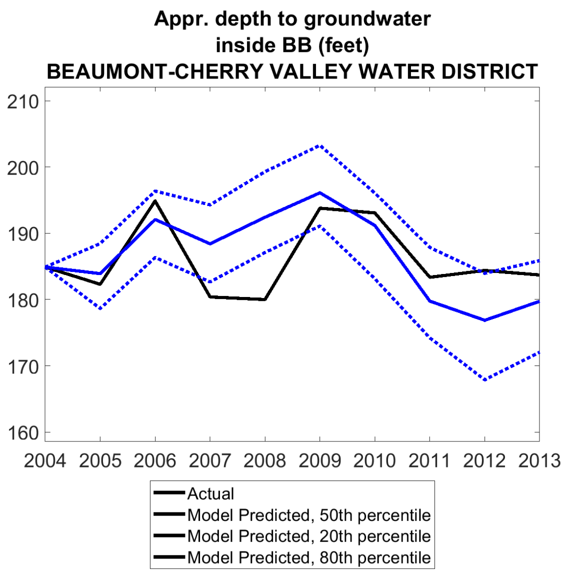



(b) City of Banning

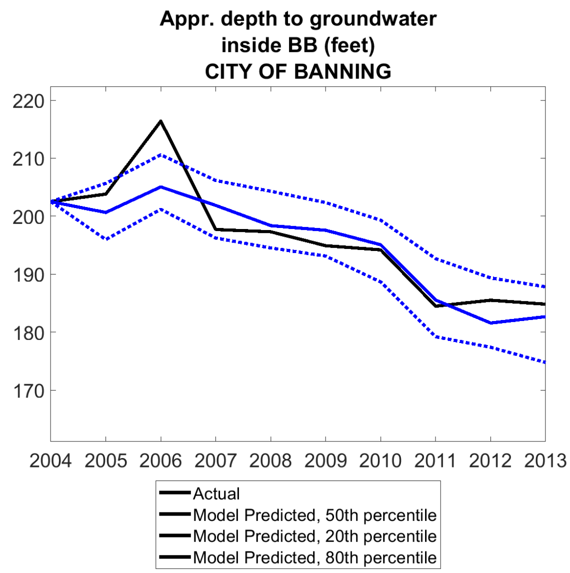



(c) Yucaipa Valley Water District

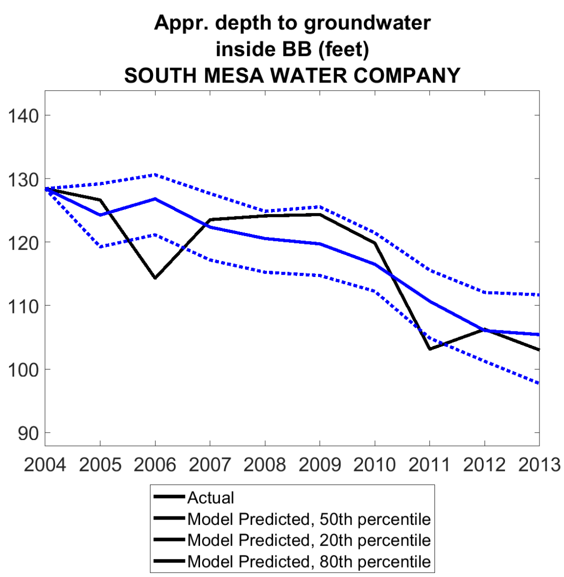
Figure A.50: No Property Right to Recharged Water Counterfactual Comparison: Appropriator Water Imports



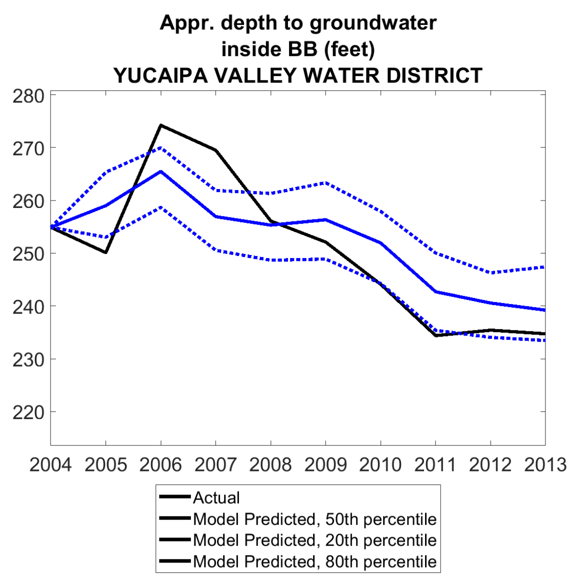

(a) Beaumont-Cherry Valley Water District




(b) City of Banning

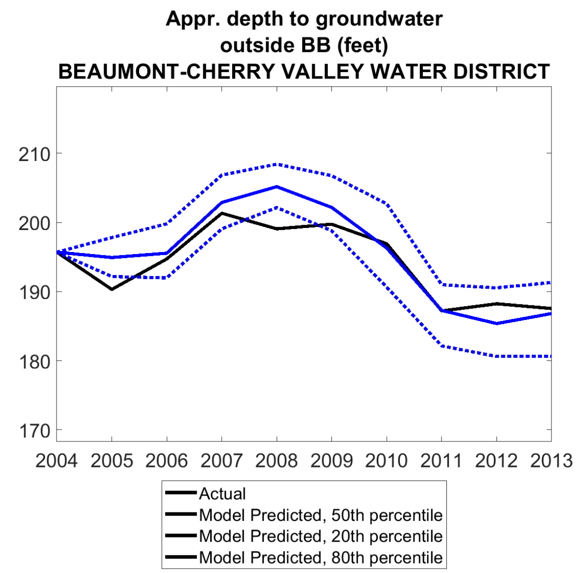



(c) South Mesa Water Company

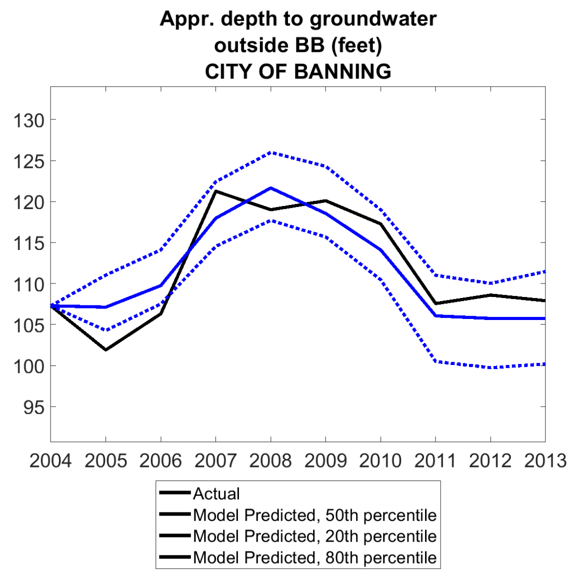



(d) Yucaipa Valley Water District

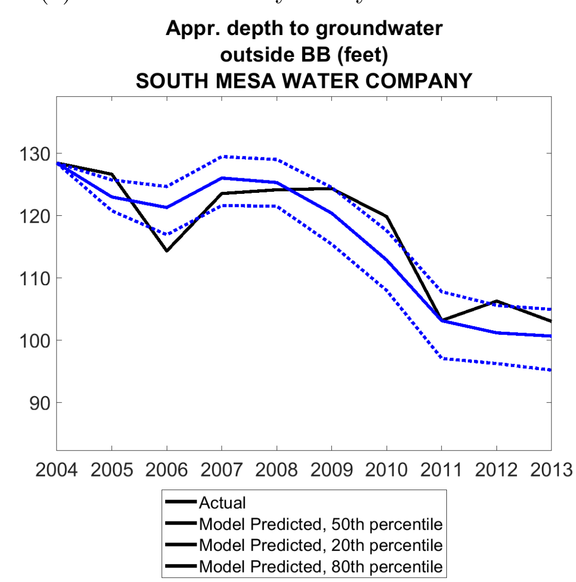
Figure A.51: No Property Right to Recharged Water Counterfactual Comparison: Appropriator Depth to Groundwater in Beaumont Basin



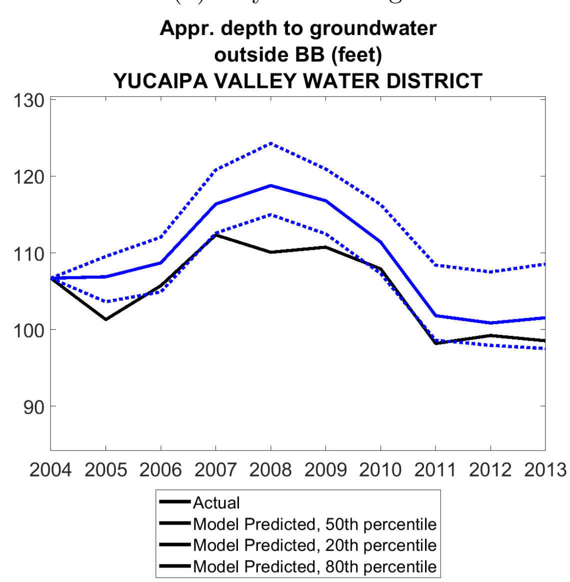

(a) Beaumont-Cherry Valley Water District




(b) City of Banning

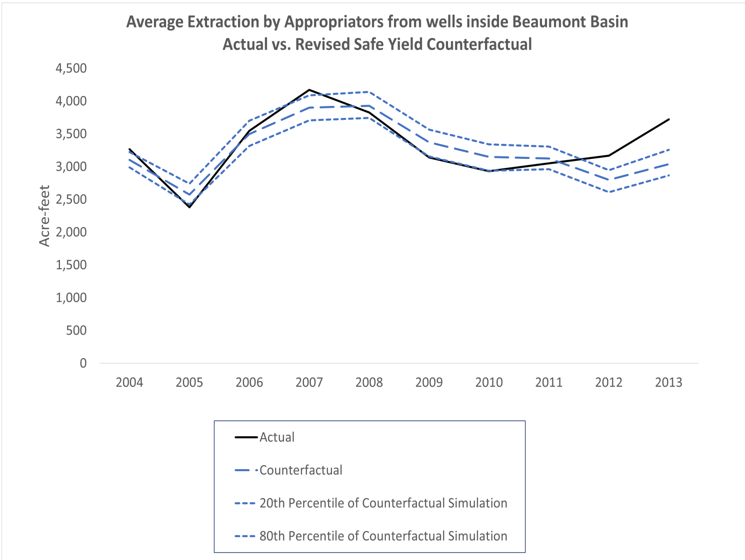



(c) South Mesa Water Company

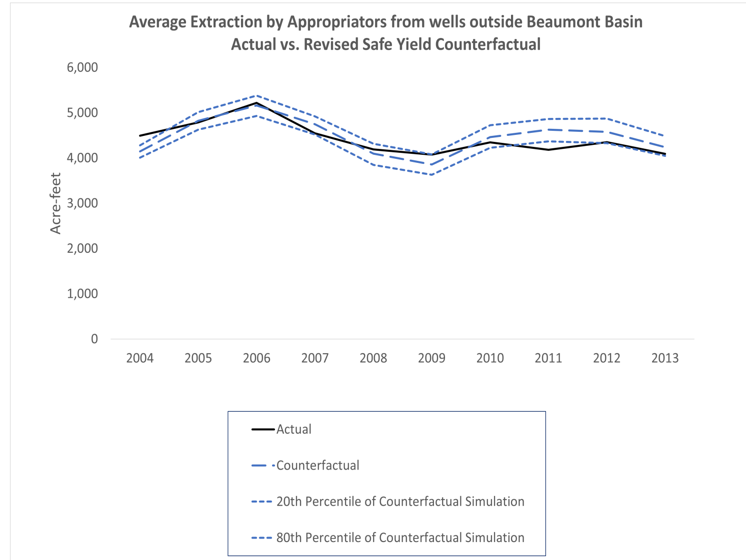



(d) Yucaipa Valley Water District

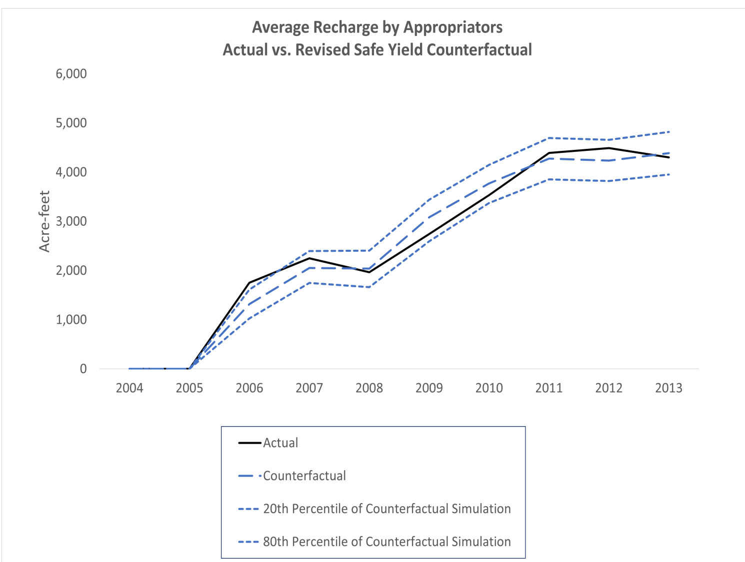
Figure A.52: No Property Right to Recharged Water Counterfactual Comparison: Appropriator Depth to Groundwater outside Beaumont Basin



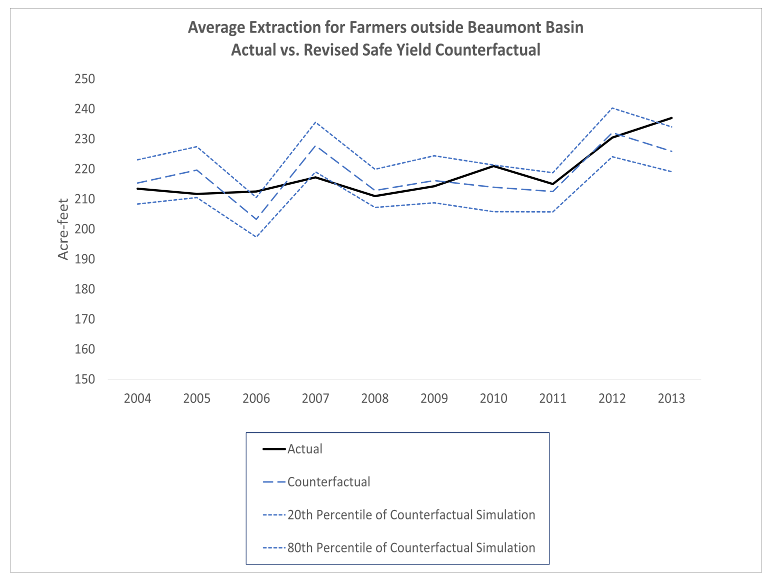

(a) Appropriator Extraction
inside Beaumont Basin




(b) Appropriator Extraction
outside Beaumont Basin

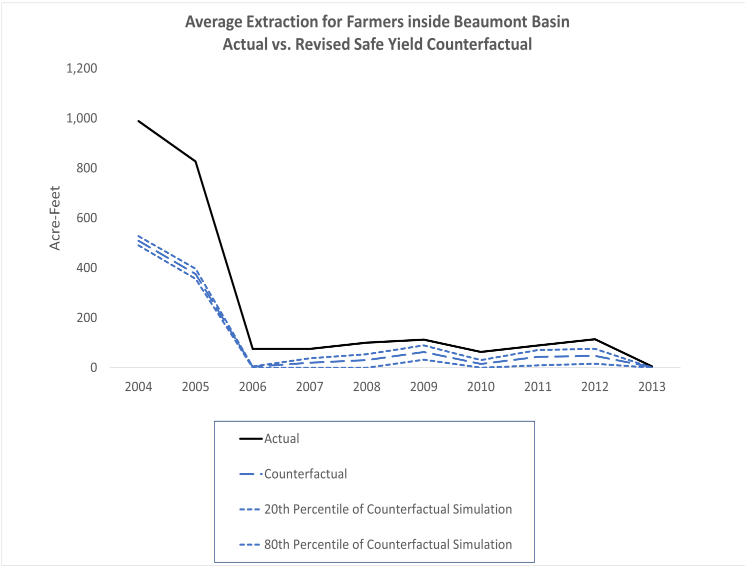



(c) Appropriator
Recharge

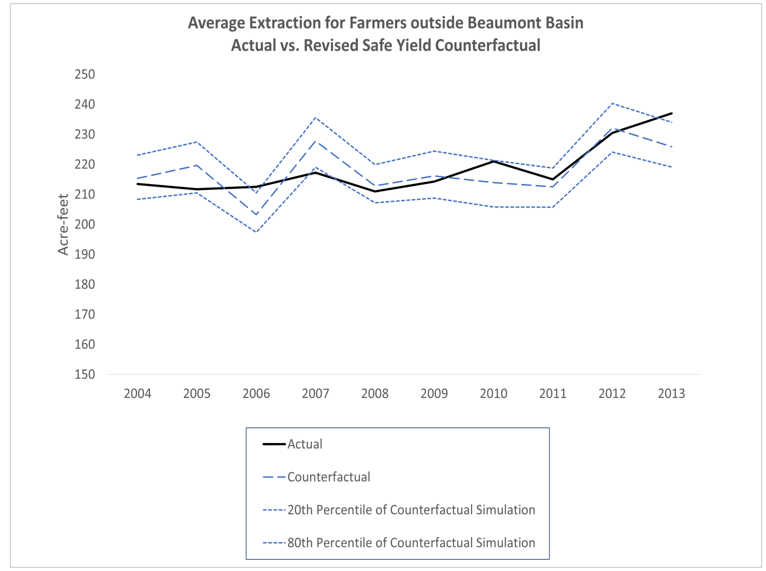



(d) Appropriator
Filtered Sales

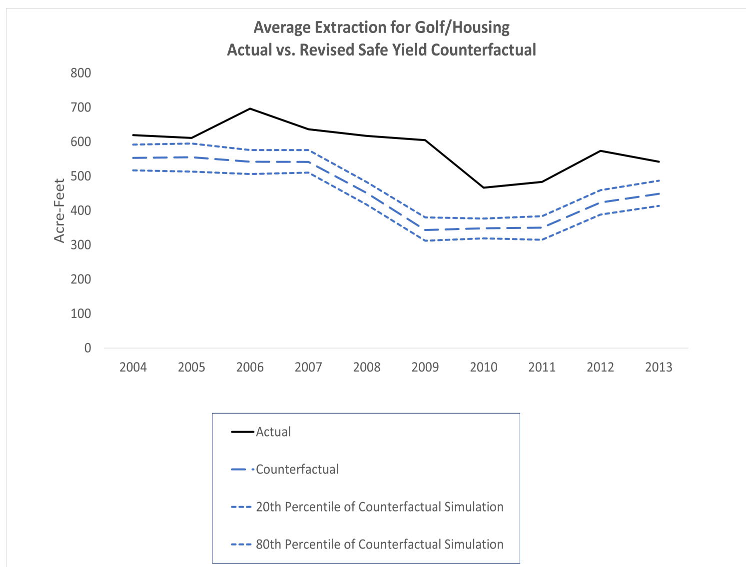
Figure A.53: Revised Safe Yield Counterfactual Comparison: Appropriator Behavior




(a) Farmer Extraction inside Beaumont Basin

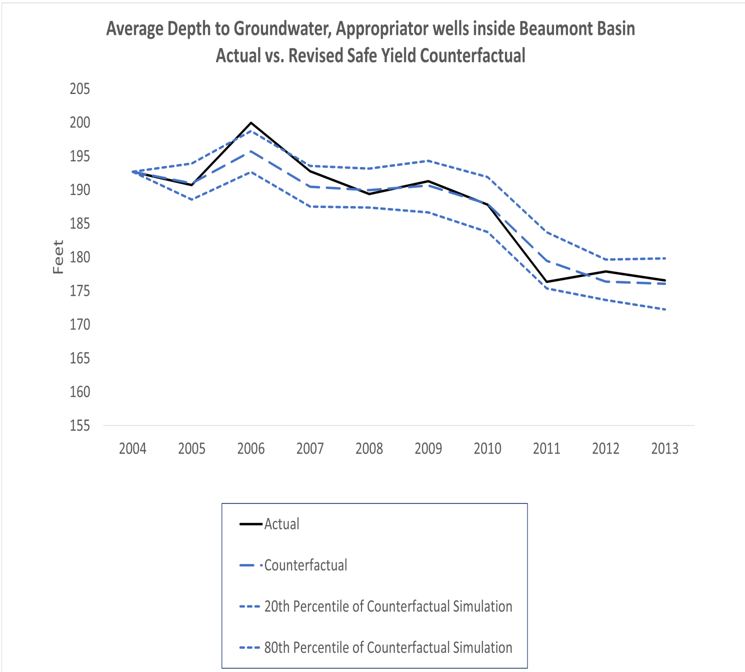



(b) Farmer Extraction outside Beaumont Basin

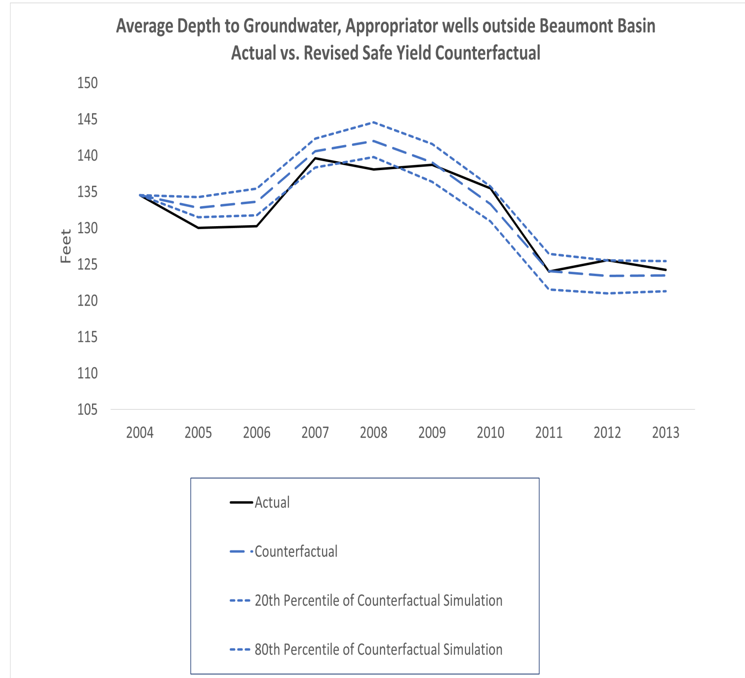



(c) Recreational User Extraction

Figure A.54: Revised Safe Yield Counterfactual Comparison: Overlyer Behavior

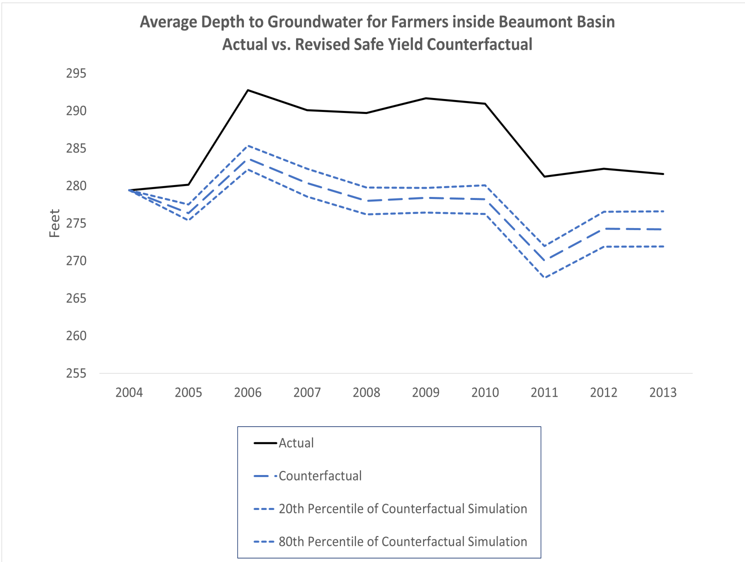



(a) Appropriator Depth to Groundwater inside Beaumont Basin

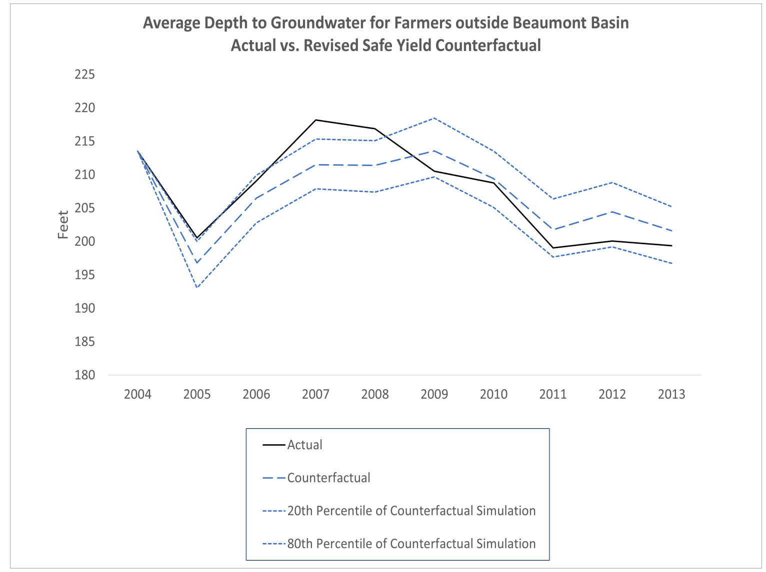



(b) Appropriator Depth to Groundwater outside Beaumont Basin

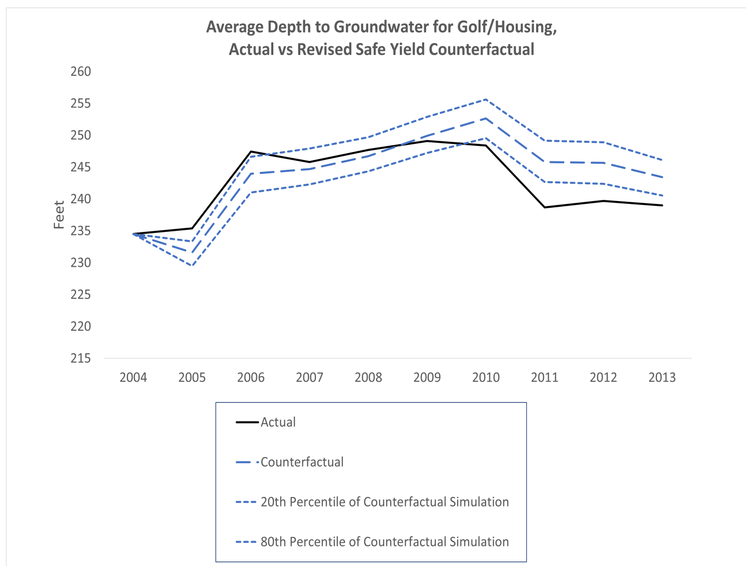
Figure A.55: Revised Safe Yield Counterfactual Comparison: Appropriator Depth to Groundwater




(a) Farmer Depth
to Groundwater
inside Beaumont Basin




(b) Farmer Depth
to Groundwater
outside Beaumont Basin




(c) Recreational User
Depth to Groundwater

Figure A.56: Revised Safe Yield Counterfactual Comparison: Overlyer Depth to Groundwater

# B Robustness Check

For our base-case specification, we estimate the well drilling policy functions using all observations, and allow for any player to drill in the simulation. As a robustness check, in an alternative specification of the well drilling policy function, we only allow drilling by appropriators and farmers, as appropriators and farmers are the only player types to drill in the data, and include a dummy variable for appropriator as a regressor. This allows us to determine whether our results are robust to our methodological choice of allowing all players to drill wells during the game.

Including all players in the specification provides additional observations, and if the model is correctly specified it in theory will provide additional variation and more precisely estimated standard errors. If recreational users (golf courses, retirement homes, and housing developments) did not drill due to an unobserved factor, however, then including them in the regression will add omitted variable bias since any unobserved factors correlated with a recreational user grouping will be negatively correlated with the dummy variable for appropriators. In addition, if depth to groundwater for the recreational user group is higher or lower than for other players then this will add an additional source of bias to our estimate for the coefficient on depth squared in our policy function regression. As overlying rights holders, golf courses and housing developments were subject to similar legal rights and constraints as farmers during this period with regard to drilling wells. Depth to groundwater for recreational players at the mean was between what we found for appropriators and farmers in the Beaumont Basin. Thus, we do not have strong prior reasons to expect that our baseline results are biased by inclusion of the full sample, however, we include this alternate specification to examine the effect of changing our specification to only include players in the groups that did drill during our sample period.

## B.1 Base Scenario Results

The change in specification alters one input in our structural model, the policy function used for well drilling which is a binary variable. In Table B.1 we display our results for the policy function. Explanatory variables are the same as in the base case as are the signs and signifciance of the variables. We then simulate the structural model but now limit well drilling as a policy option to just farmers and appropriators. Examining our mean simulation results in Table B.2 we see that across action variables our results are not substantially different from our baseline simulation. The distribution of extraction by appropriators between basins remains tilted towards basins outside of Beaumont. Similarly farmers inside Beaumont still tend to extract more than farmers outside of Beaumont. The sign of differences at the mean between our baseline results and results in our robustness check also remain the same. Looking at values of the state variable depth to groundwater, we see once again that results remain very close between the two simulations.

We compare the trajectories of action choices by each of the player groups in Figures B.1-B.2. We see that the paths of these averages are consistent with what we found in the baseline simulation using our main specification. Thus, our our action results follow the same trends as both the observed data and our main specification. Examining depth to groundwater in Figures B.3-B.4 we see that depth to groundwater follows similar trends in both the main specification and in our robustness check. Finally we can further disaggregate to the individual player level in Figures B.5-B.13.

We find that our simulated data track closely with what we found in the original specification. Whether that translates into similar welfare results depends on how close our structural parameter estimates are to our main specification. In Table B.3 we show estimates of the revenue function parameters. For farmers, our coefficients all have the same sign, although they are greater in magnitude and less precisely estimated. For golf courses and housing developments the pattern is similar, which leads to larger differences in profitability between different types of extractors in the of player group. For appropriators we find that appropriators are less sensitive to weather disruptions and that the consumer surplus weighting curve is slightly flatter than in the main specification.

Looking next at the cost function parameter estimates in Table B.4, we find that the signs and relative magnitudes of the parameter estimates for the quadratic extraction terms are consistent with our findings in the main specification. However, now coefficient for appropriators is no longer statistically significant, while the coefficient for golf courses and housing developments is significant. Our parameter estimate for the cost of well drilling is now a little over half the value we found in the main specifiaction. This suggests that including all players does influence the estimated cost of drilling, suggesting that is more expensive.

Finally we examine the value of imported water and property rights in Table B.5. We see that the sign of the average value of property rights for appropriators switches signs, although it is not statistically significant in either the robustness check or the main specification. Average effects are consistent in sign, relative magnitudes, and significance for all other variables betweeen the robustness check and the main specification. We do see that the spread in value between recharge and filtered sales is larger in the robustness check, suggesting a smaller additional perceived value for appropriators from recharging water vs. selling it to customers.

We now turn to the welfare implications of our results. In Table B.6 we present our average annual welfare results for the baseline simulation in our robustness check. We find that our model predicted and actual welfare are somewhat higher in the robustness check for appropriators and farmers in the Beaumont basin, while results are close to the main specification for all other players. This is likely due in part to lower costs for well drilling and slight changes in the consumer surplus weighting results. However the magnitudes are generally close and differences across players and player groups are preserved. In Table B.7 we see that this is indeed driven by higher profits for players which includes the effect of well drilling costs. In Table B.9 we see that total social welfare is estimated to be about 1 million dollars higher per year under the robustness check vs. the main specification, with this coming from higher producer profits from appropriators.

## B.2 Counterfactual Analysis

We then conduct counterfactual analysis that mirrors our main specification's analysis. We simulate the same eight counterfactuals and document the trajectores for extraction and depth to groundwater along with welfare results from each counterfactual. We can then compare these with our main specification results and attribute differences to our change in specification. This allows us to determine whether changing specification interacts with any of our counterfactual assumptions to produce differences in welfare levels.

Results for our "No Artificial Recharge Counterfactual" can be found in Tables B.10-B.12. Results for our "No Filtered Sales Counterfactual" are shown in Tables B.13-B.15. Results for our "No Trading Counterfactual" are found in Tables B.16-B.18. Results for our "No Imports Counterfactual" are shown in Tables B.19-B.21. The "No Imports or Trading Counterfactual" results are found in Tables B.22-B.24. We present the "Equal Initial Property Rights Allocation Counterfactual" in Tables B.25-B.27. Results for the "No Property Right to Recharged Water Counterfactual" are in Tables B.28-B.30. Finally, results for the "Revised Safe Yield Counterfactual"are in Tables B.31-B.33.

Highlighting some of our results, we find that across specifications that counterfactual producer surplus is around $1 million higher in our robustness simulations vs. our main specification. Since this is similar to the magnitude of difference between our baseline simulations and the quantities we obtain from the actual data, our welfare differences are very close to what we obtained from the main specification. The difference in counterfactual producer surplus is driven by a difference for appropriators. This is likely due to lower welfare losses in years with higher evapotranspiration as seen in our discusion of the parameter estimates. While well drilling is now cheaper, there is relatively little drilling during this period and so a difference of this scale in welfare is unlikely to be explained by differences in drilling and its cost. We do not see significant differences with what we found for consumer surplus, the value of property rights, or the value of imported water. Furthermore, since the difference in welfare is similar across simulations and in the actual data, this suggests that we are not observing a large effect of well drilling on other action choices, but instead the effects of changes in our parameter estimates.

We find that when we remove filtered sales our robustness check leads to a small shift in Beaumont Basin extraction from farmers to appropriators relative to our baseline results. We find similar results when we remove property rights trades, along with a slightly lower level of artificial recharge. When we remove all imported water, we find similar results to our baseline. This is also the case when we combine removing imports and trading. Moving to property rights design, we find that allocating water rights equally across appropriators extraction inside of Beaumont shifts from appropriators to farmers, and slightly lower levels of recharge in our robustness case. This is also the case when we remove property rights to recharged water. When we revise the safe yield we find that there is a slight shift in extraction by appropriators to wells inside Beaumont in our robustness case. In our robustness case we also find lower recharge and lower extraction by farmers inside Beaumont. Overall the changes in each robustness check of the counterfactuals are small and do not influence our qualitative results. By making well drilling somewhat less frequent players did less to conserve resources in Beaumont in some cases by recharging less and extracting more, but this was not true across player groups. Depth to groundwater was also not substantially impacted by our change in policy functions. Thus our robustness check results help to confirm that our findings are not sensitive to our selection of well drilling policy function.

## B.3 Discussion

Overall our results tell a similar story to what we found in our main specification. In particular wthe trajectories of action and state variables are robust to the well drilling policy function specification. Nevertheless, the change in magnitude for our well drilling cost parameter does suggest that there could be unobserved variation between player groups that affected the propensity of recreational players to drill. Since these players had relatively higher depth to groundwater this also impacted our policy function coefficients slightly and may have had an influence on changing our structural parameter estimate. However, the overall impact of these changes on welfare was small and did not interact with our counterfactual assumptions. Since well drilling was infrequent in general (which was the main reason for running a robustness check in the first place) the welfare implications of changes to our specificaiton for well drilling are not likely to make a large difference, however, this could be an important issue in other contexts, or in future years when well drilling could be a more frequent occurence. Thus, it could be useful to further investigate sources for variation in well drilling responses across different types of groundwater users.

Table B.1: Robustness Check: Policy Function Results, 2004-2013

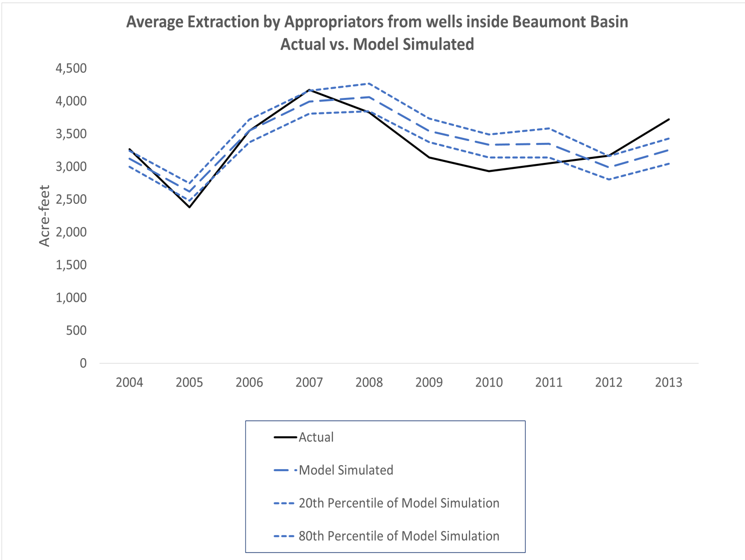
| | *Dependent variable is:* Well drilling (dummy) |
|---|---|
| | (1) |
| Depth to groundwater squared, feet | -4.72e-05*** |
| | (0.00000747) |
| Appropriator (dummy variable) | -0.802** |
| | (0.3) |
| Probit | Y |
| # Observations | 100 |
| # Players | 10 |

Notes: Standard errors in parentheses. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

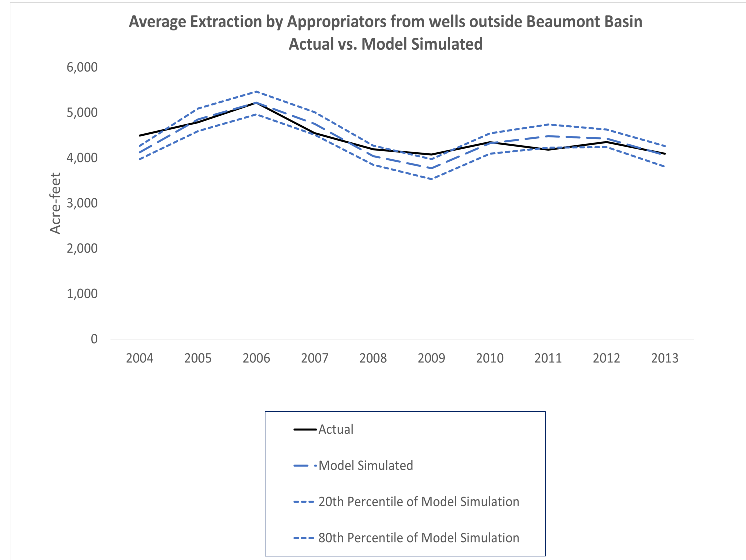
Table B.2: Robustness Check: Model Fit Simulation Statistics, 2004-2013

| | Appropriator inside Beaumont | Appropriator outside Beaumont | Farmer inside Beaumont | Farmer outside Beaumont | Golf Course / Housing Development | Appropriator Imported Water |
|---|---|---|---|---|---|---|
| | | | *Groundwater Extraction (acre-feet)* | | | *Artificial Recharge (acre-feet)* |
| Model Simulated Data | | | | | | |
| Mean | 3385.58 | 4399.85 | 276.36 | 218.57 | 518.86 | 3610.59 |
| Std Dev | 3496.15 | 2723.11 | 379.68 | 218.57 | 434.65 | 2369.43 |
| Actual Data After Institution of Property Rights | | | | | | |
| Mean | 3319.90 | 4426.40 | 257.42 | 218.38 | 590.17 | 3631.94 |
| Std Dev | 3621.51 | 2776.24 | 391.34 | 152.58 | 418.02 | 2508.99 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | 0.020 | -0.006 | 0.129 | 0.001 | -0.001 | -0.006 |
| Std Dev | 0.199 | 0.149 | 0.303 | 0.120 | 0.237 | 0.318 |
| | | | *Depth to Groundwater (feet)* | | | *Filtered Sales (acre-feet)* |
| Model Simulated Data | | | | | | |
| Mean | 187.99 | 132.87 | 283.80 | 208.17 | 242.07 | 4729.88 |
| Std Dev | 48.73 | 37.08 | 84.89 | 208.17 | 87.46 | 2440.46 |
| Actual Data After Institution of Property Rights | | | | | | |
| Mean | 187.54 | 132.05 | 285.98 | 207.59 | 242.57 | 4754.30 |
| Std Dev | 48.36 | 36.70 | 86.69 | 47.85 | 83.64 | 2222.38 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | 0.002 | 0.006 | -0.008 | 0.003 | -0.003 | -0.005 |
| Std Dev | 0.048 | 0.044 | 0.015 | 0.062 | 0.034 | 0.150 |

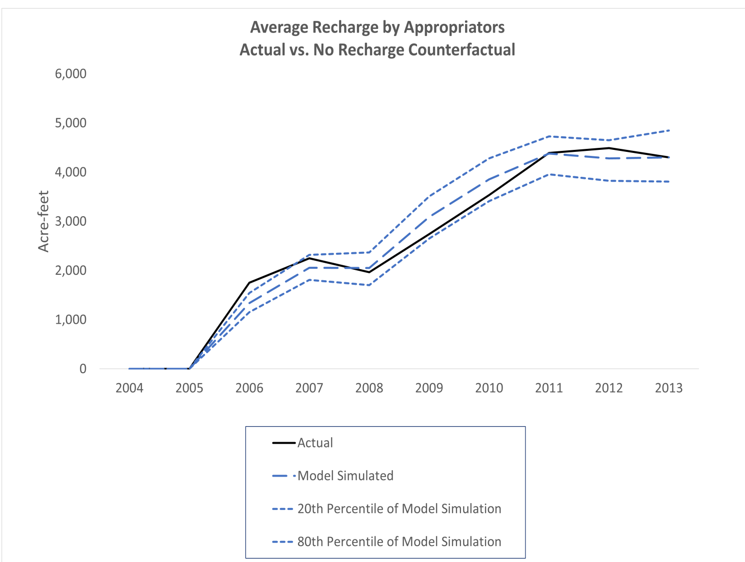
Notes: This table compares the counterfactual actions and states with the actual and Base scenario actions and states.



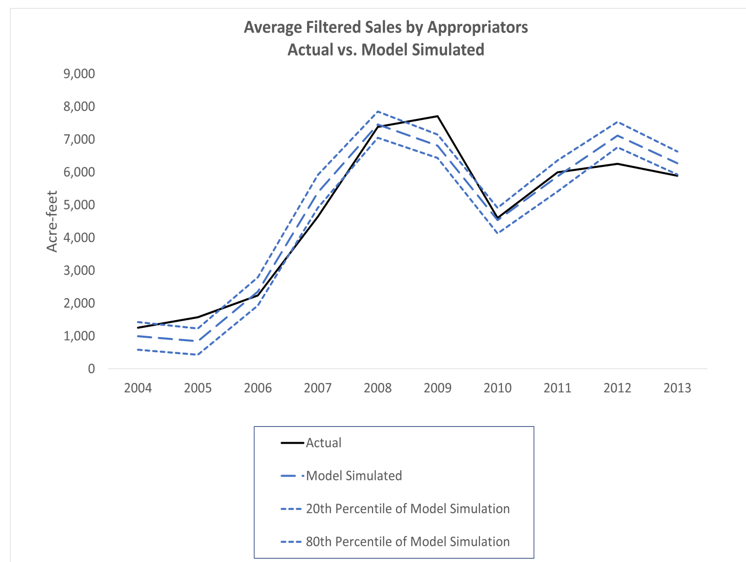

(a) Appropriator Extraction inside Beaumont Basin




(b) Appropriator Extraction outside Beaumont Basin

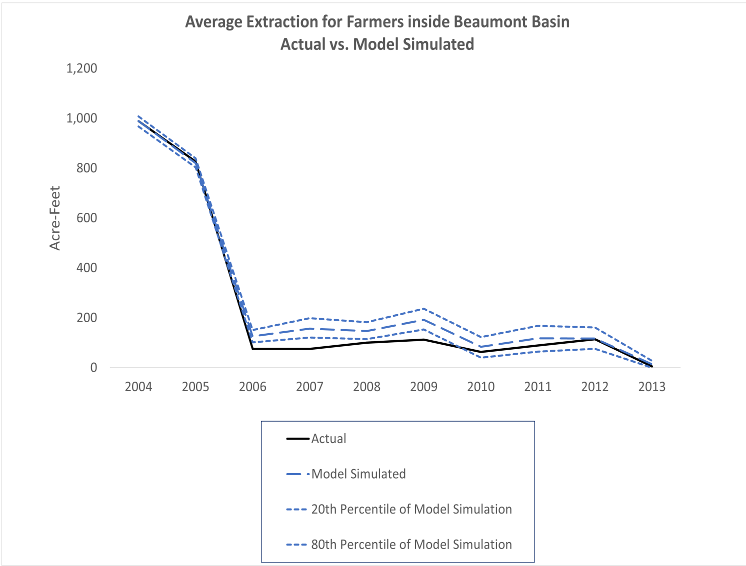



(c) Appropriator Recharge

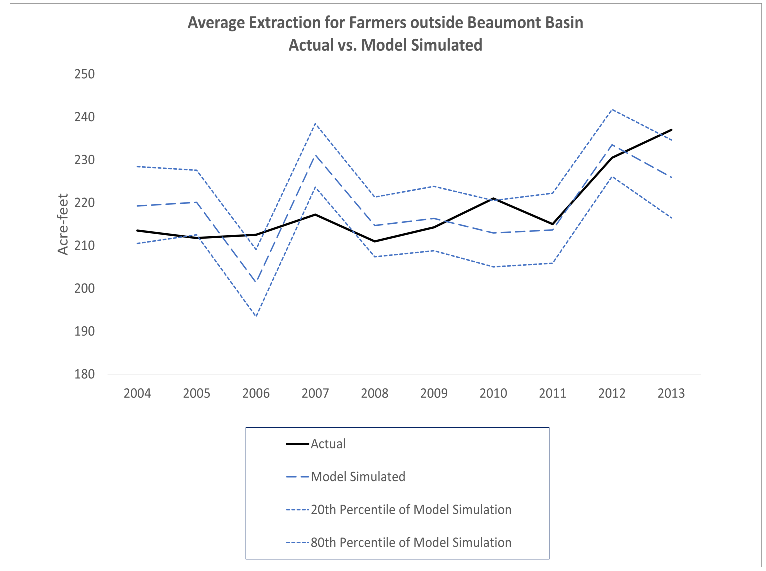



(d) Appropriator Filtered Sales

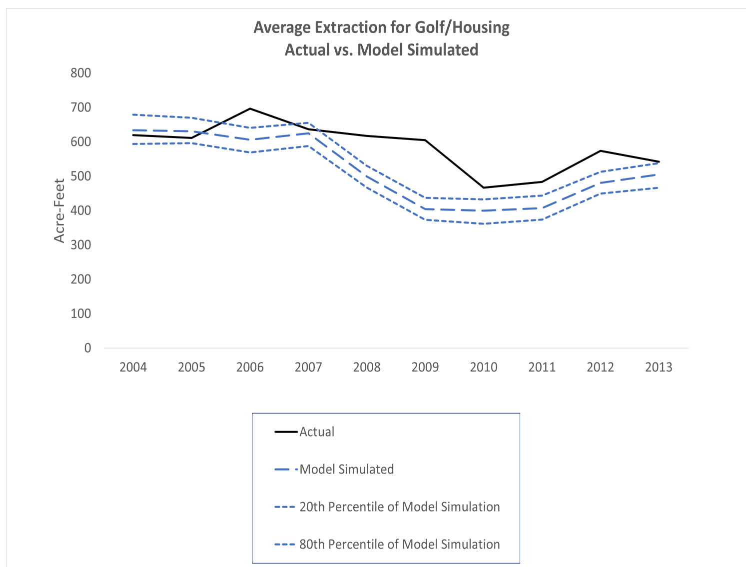
Figure B.1: Robustness Check: Model Fit: Appropriator Behavior




(a) Farmer Extraction inside Beaumont Basin

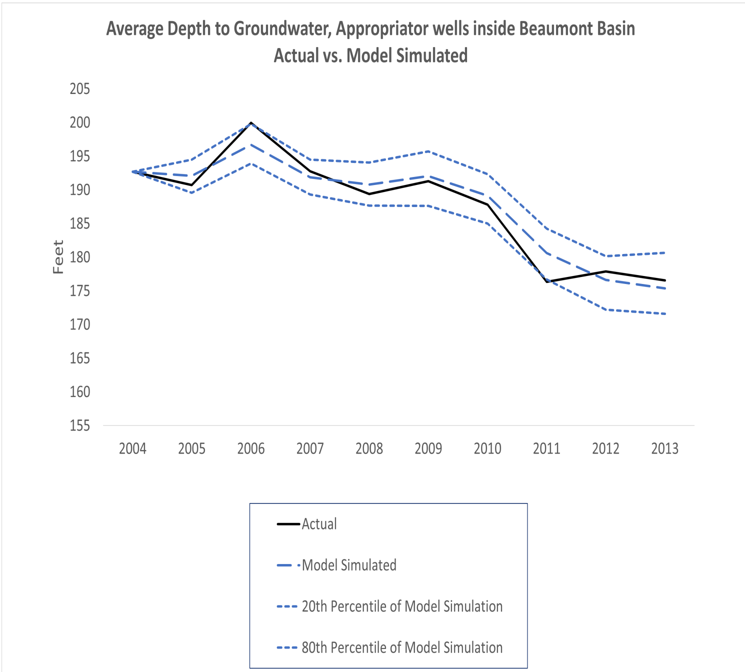



(b) Farmer Extraction outside Beaumont Basin

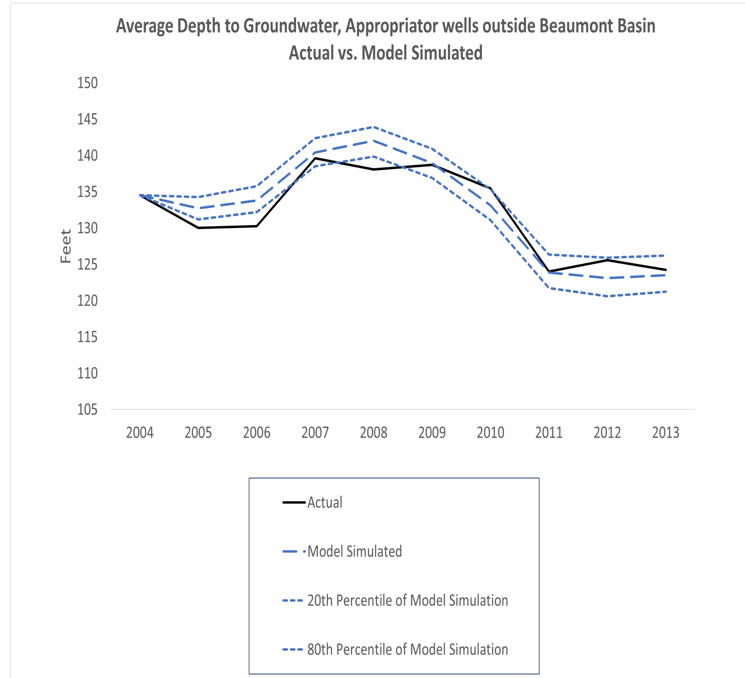



(c) Recreational User Extraction

Figure B.2: Robustness Check: Model Fit: Overlyer Behavior

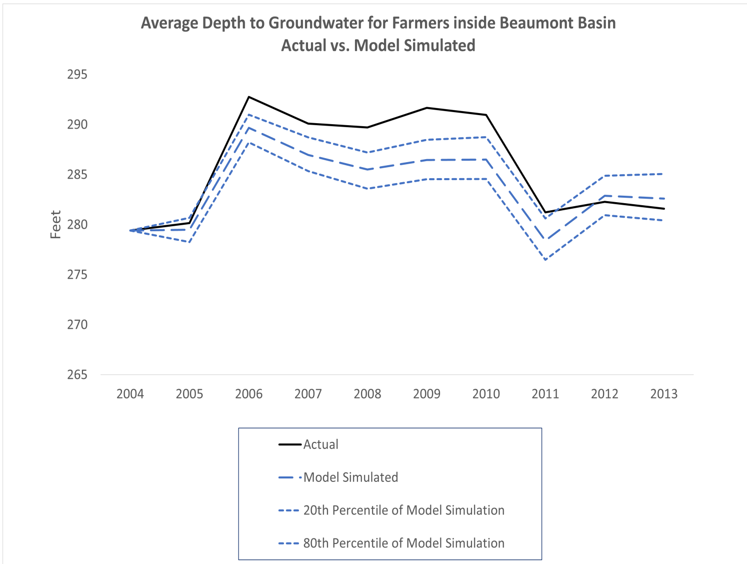



(a) Appropriator Depth to Groundwater inside Beaumont Basin

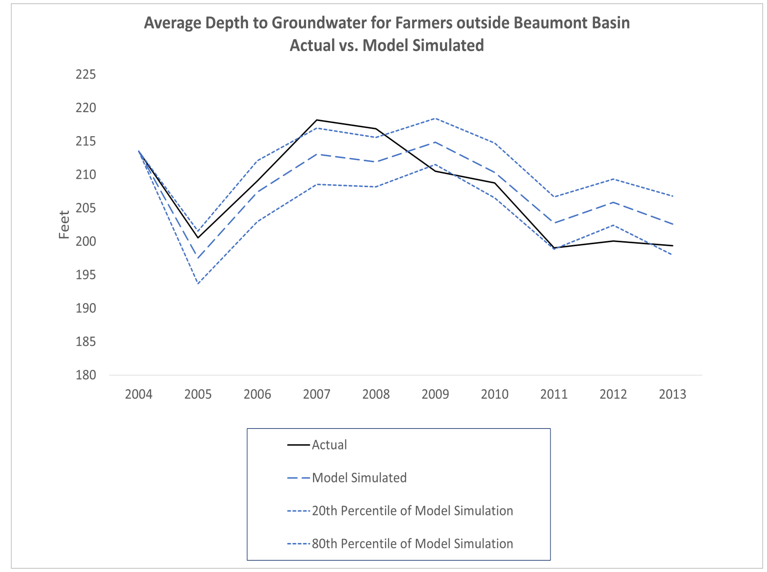



(b) Appropriator Depth to Groundwater outside Beaumont Basin

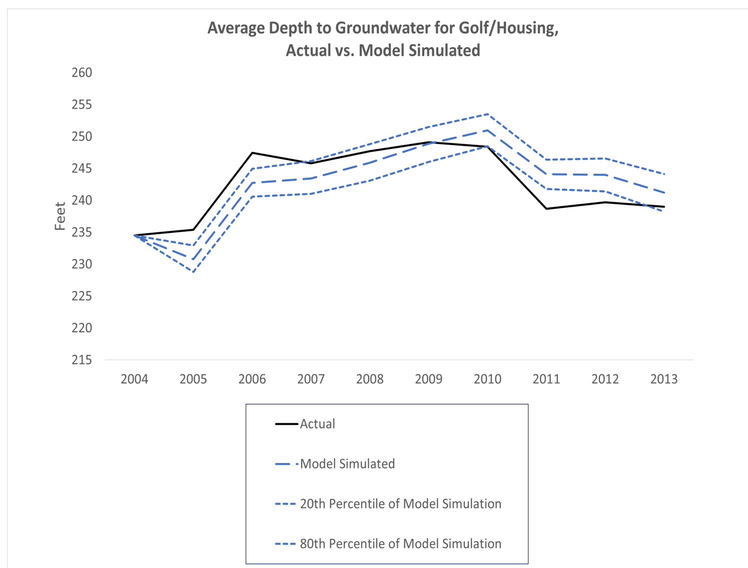
Figure B.3: Robustness Check: Model Fit: Appropriator Depth to Groundwater




(a) Farmer Depth to Groundwater inside Beaumont Basin

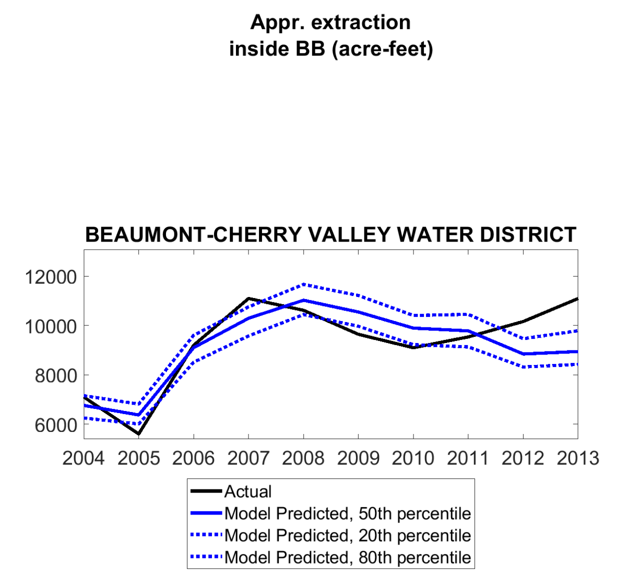



(b) Farmer Depth to Groundwater outside Beaumont Basin

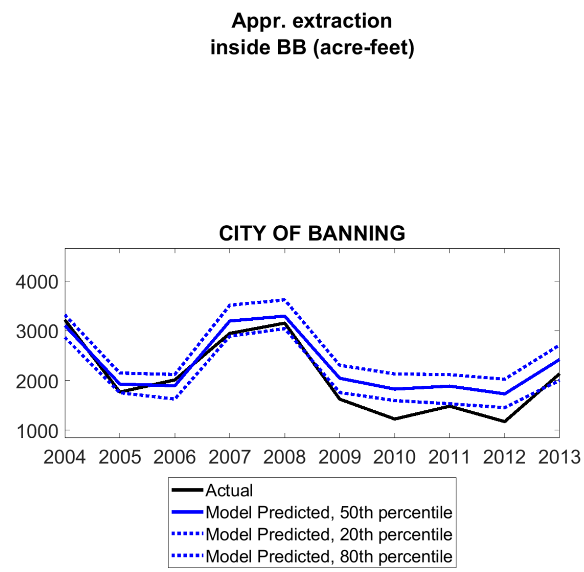



(c) Recreational User Depth to Groundwater

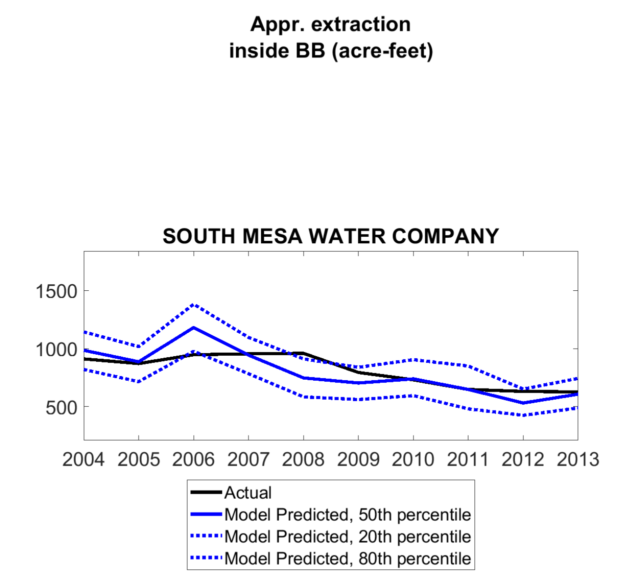
Figure B.4: Robustness Check: Model Fit: Overlyer Depth to Groundwater



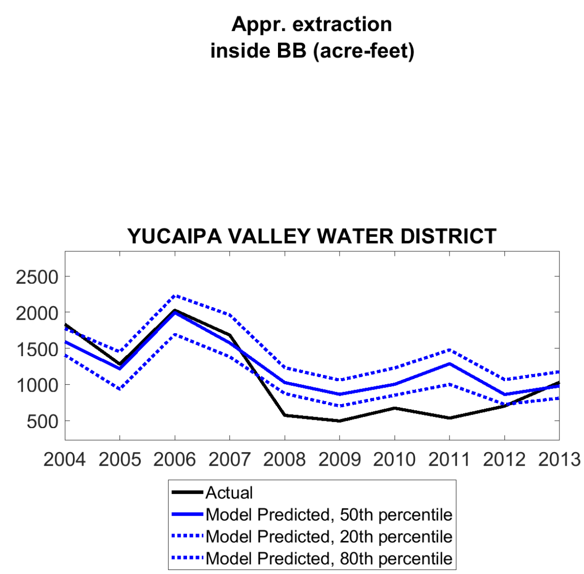

(a) Robustness Check: Beaumont-Cherry Valley Water District




(b) Robustness Check: City of Banning

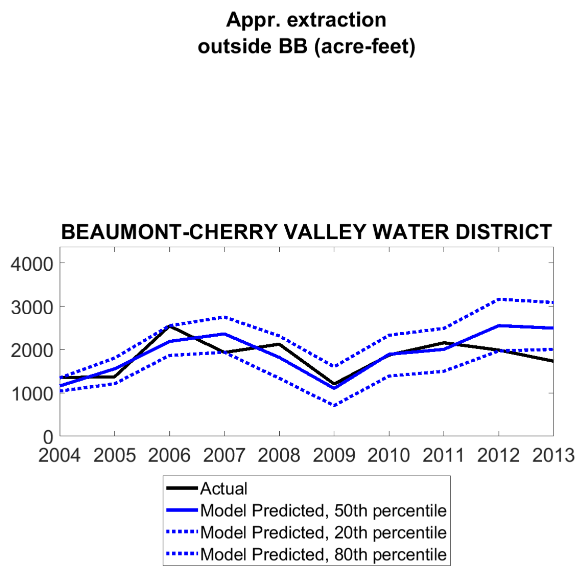



(c) Robustness Check: South Mesa Water Company

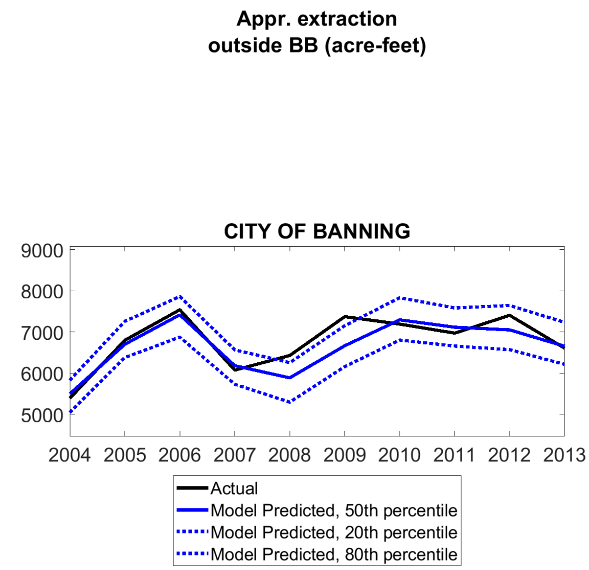



(d) Robustness Check: Yucaipa Valley Water District

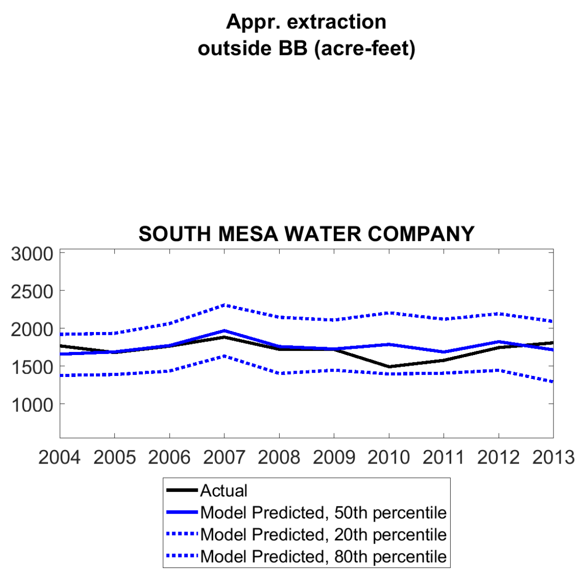
Figure B.5: Robustness Check: Model Fit Comparison: Appropriator Extraction in Beaumont Basin



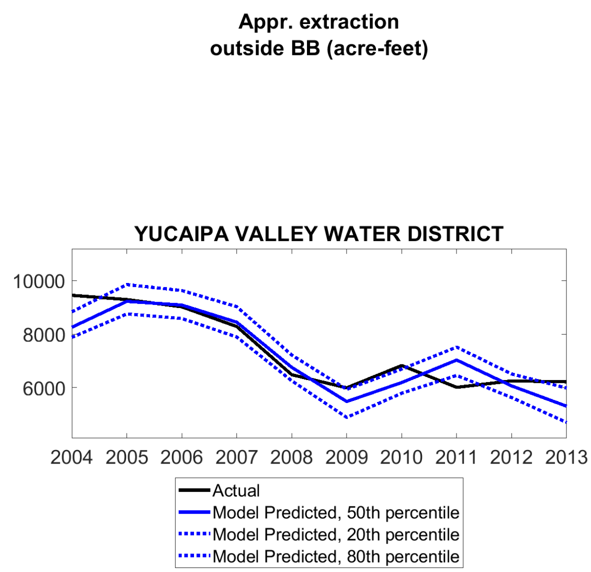

(a) Robustness Check: Beaumont-Cherry Valley Water District




(b) Robustness Check: City of Banning

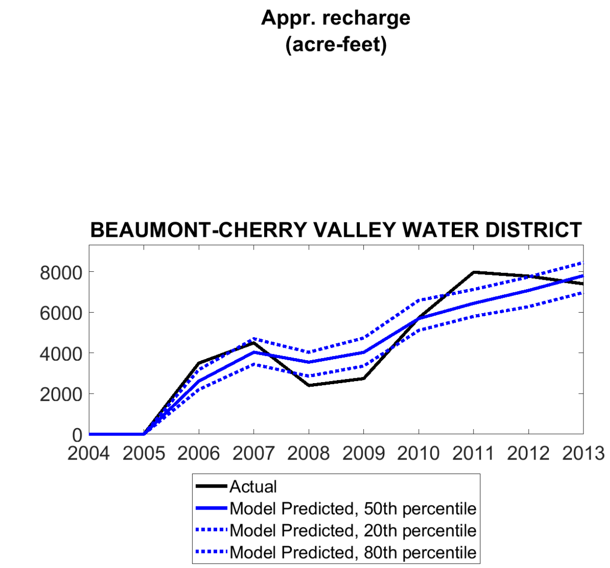



(c) Robustness Check: South Mesa Water Company

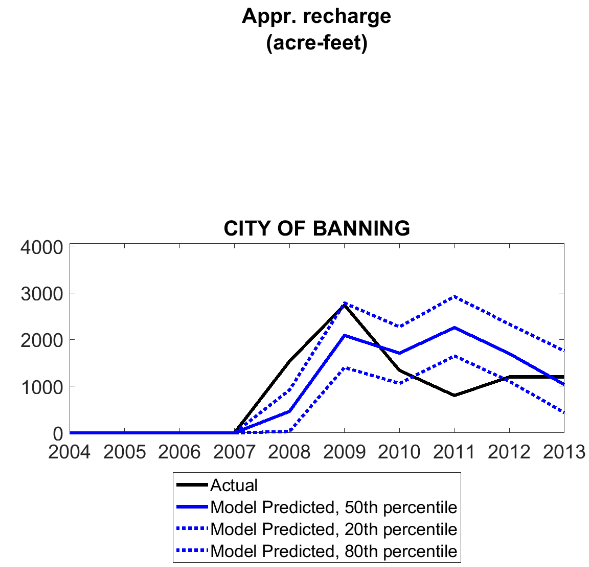



(d) Robustness Check: Yucaipa Valley Water District

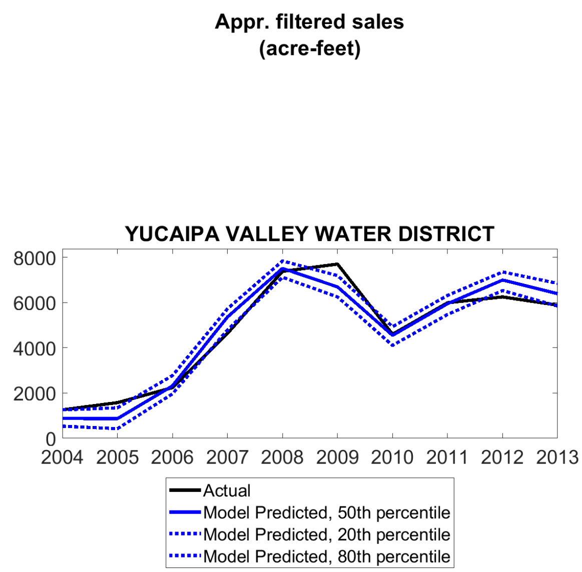
Figure B.6: Robustness Check: Model Fit Comparison: Appropriator Extraction outside Beaumont Basin




(a) Robustness Check: Beaumont-Cherry Valley Water District

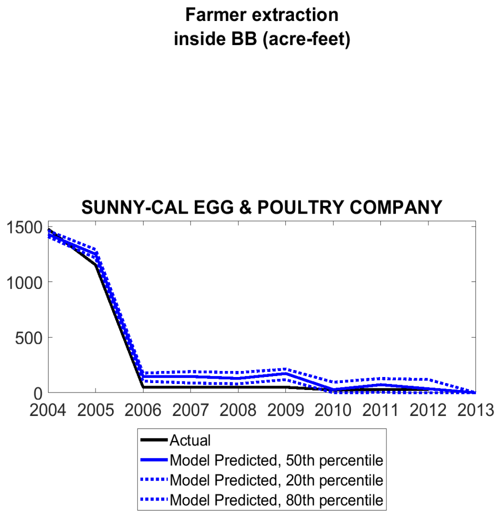



(b) Robustness Check: City of Banning

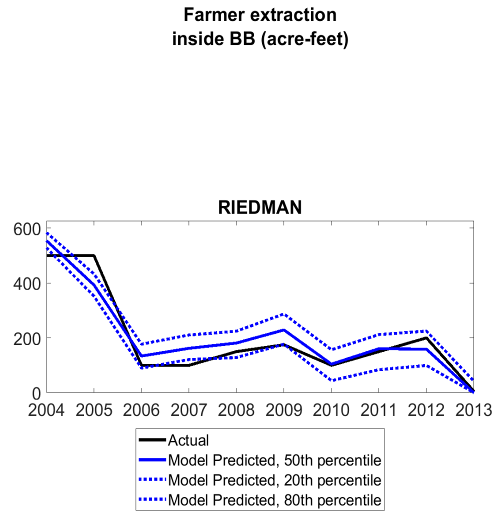



(c) Robustness Check: Yucaipa Valley Water District

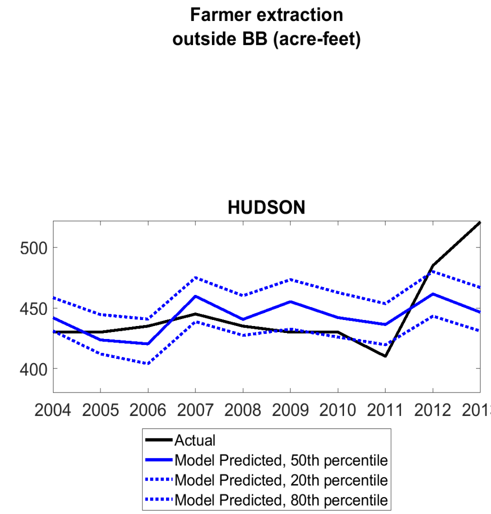
Figure B.7: Robustness Check: Model Fit Comparison: Appropriator Water Imports



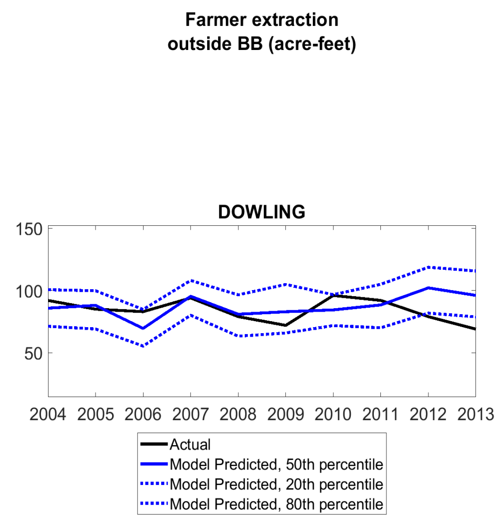

(a) Robustness Check: Sunny-Cal Egg Co.



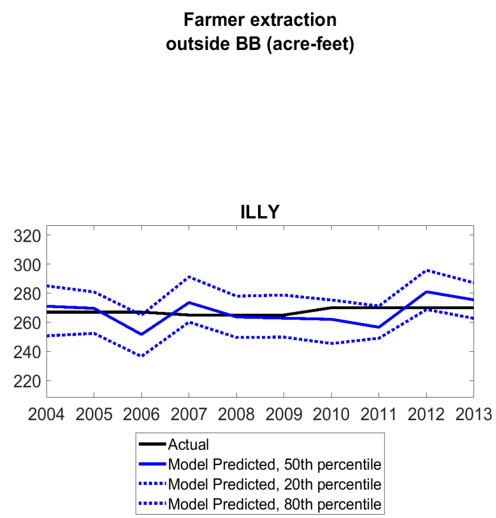

(b) Robustness Check: Riedman



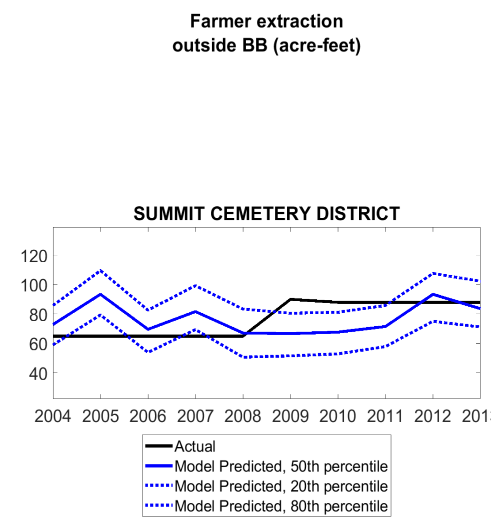

(c) Robustness Check: Hudson




(d) Robustness Check: Dowling

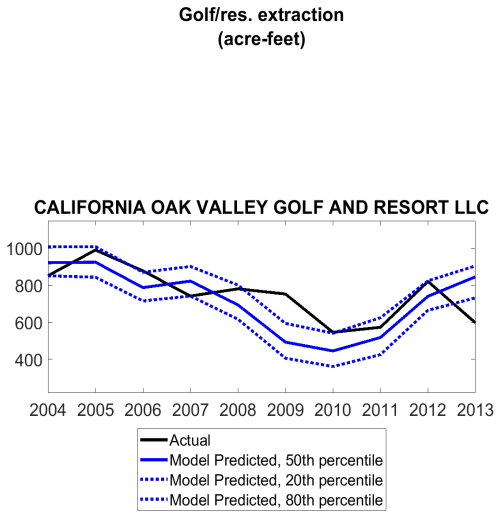



(e) Robustness Check: Illy

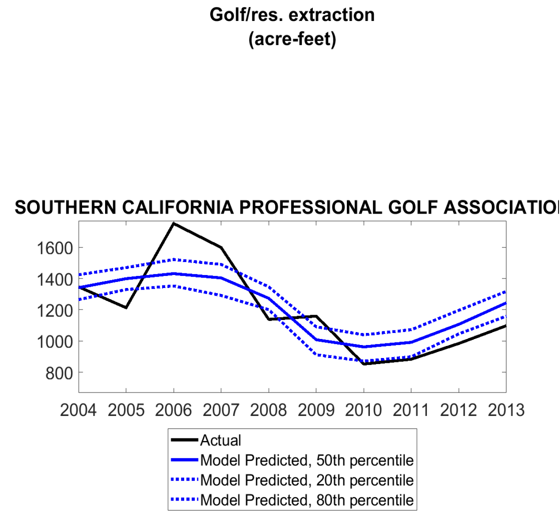



(f) Robustness Check: Summit Cemetery District

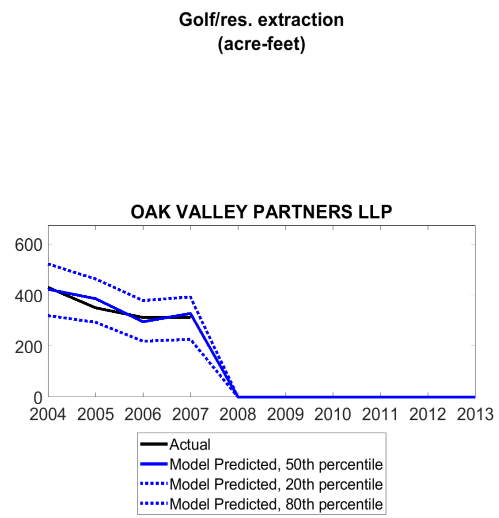
Figure B.8: Robustness Check: Model Fit Comparison: Farmer Extraction



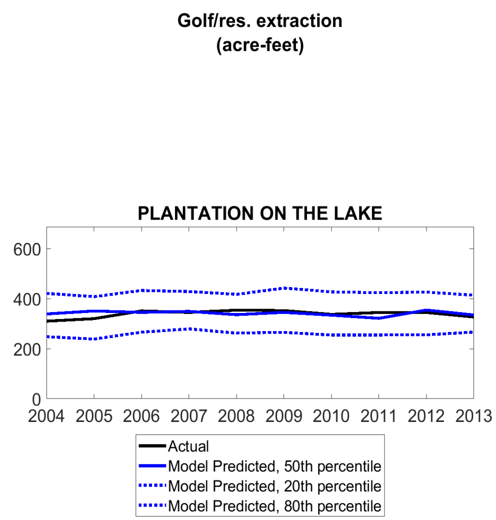

(a) Robustness Check: California Oak Valley Golf and Resort LLC



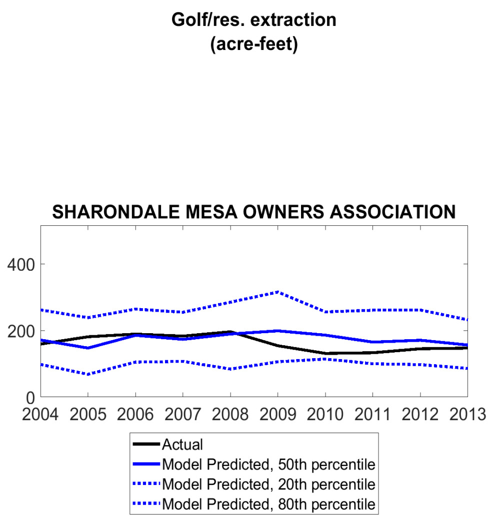

(b) Robustness Check: Southern California PGA




(c) Robustness Check: Oak Valley Partners LLP

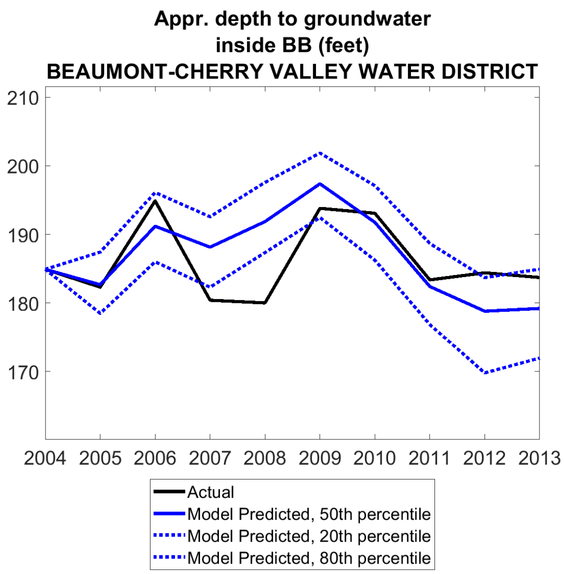



(d) Robustness Check: Plantation on the Lake

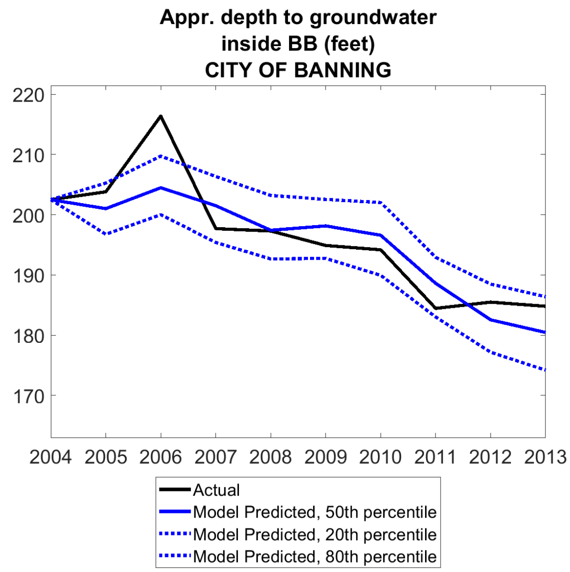



(e) Robustness Check: Sharondale Mesa Owners Association

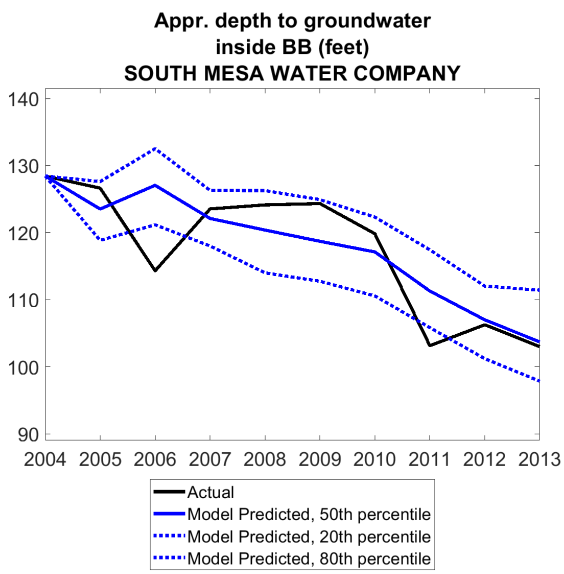
Figure B.9: Robustness Check: Model Fit Comparison: Recreational User Extraction



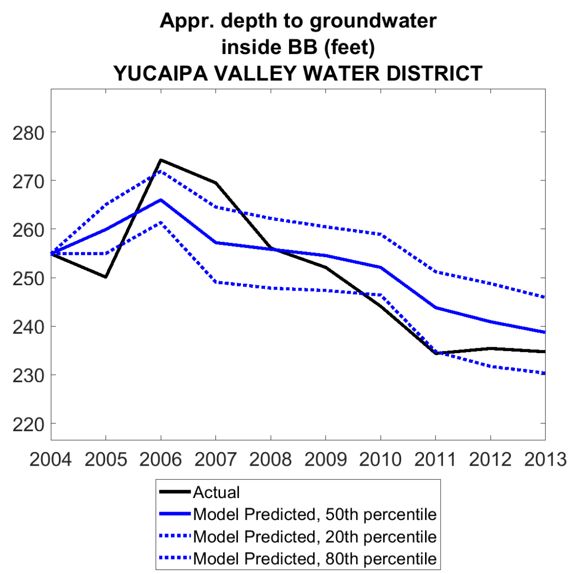

(a) Robustness Check: Beaumont-Cherry Valley Water District




(b) Robustness Check: City of Banning

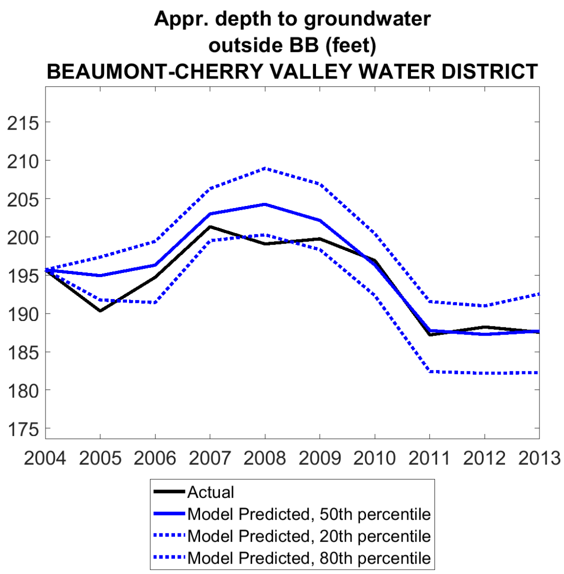



(c) Robustness Check: South Mesa Water Company

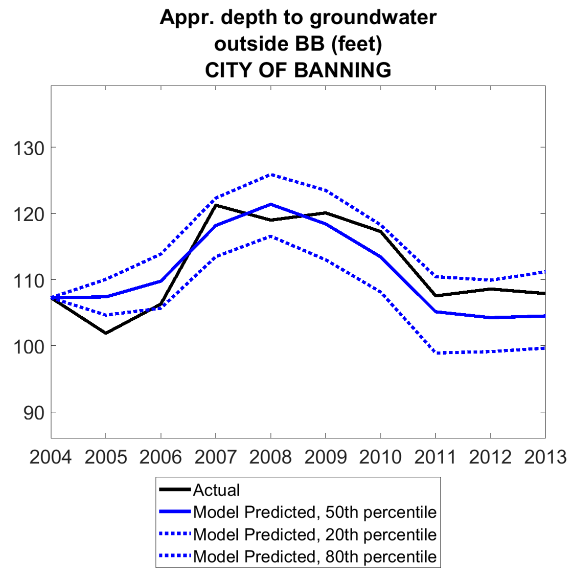



(d) Robustness Check: Yucaipa Valley Water District

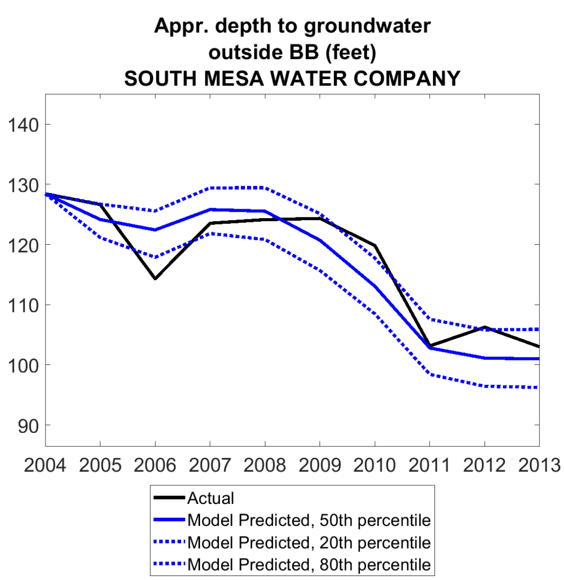
Figure B.10: Robustness Check: Model Fit Comparison: Appropriator Depth to Groundwater in Beaumont Basin



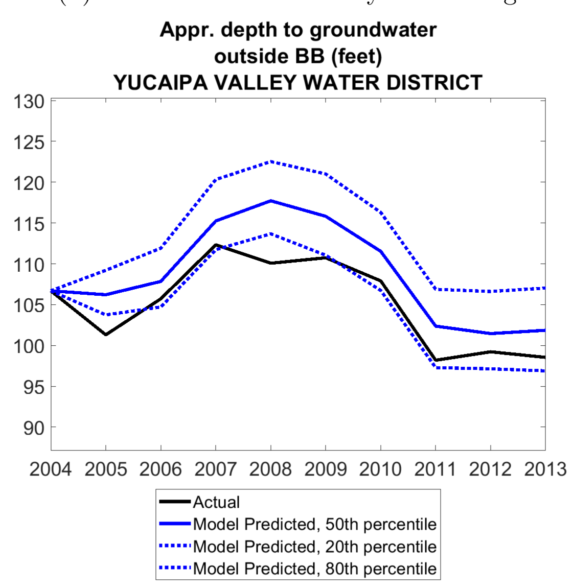

(a) Robustness Check: Beaumont-Cherry Valley Water District




(b) Robustness Check: City of Banning

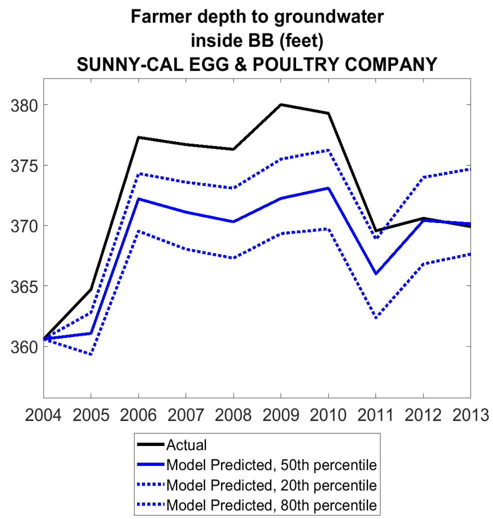



(c) Robustness Check: South Mesa Water Company

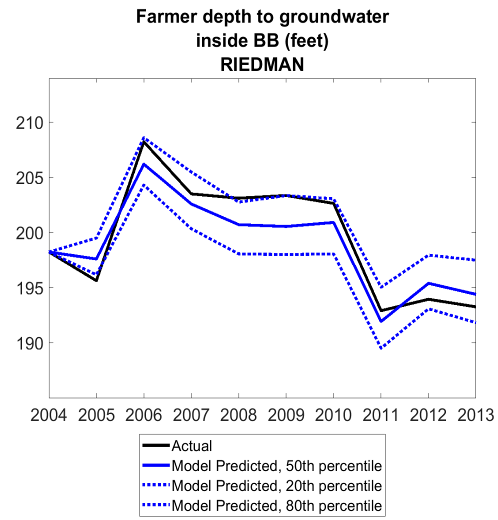



(d) Robustness Check: Yucaipa Valley Water District

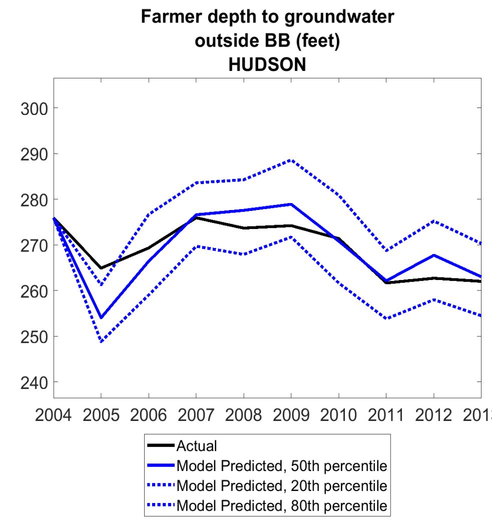
Figure B.11: Robustness Check: Model Fit Comparison: Appropriator Depth to Groundwater outside Beaumont Basin



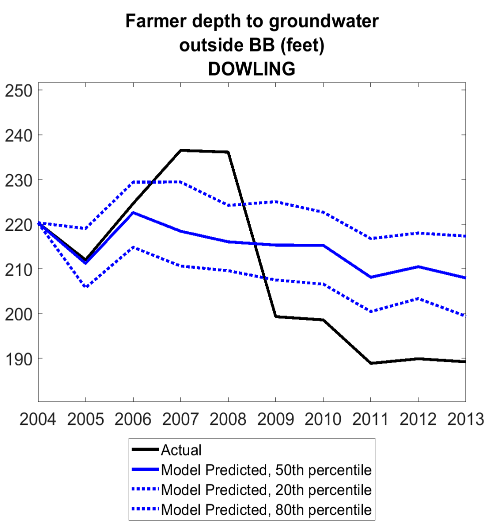

(a) Robustness Check: Sunny-Cal Egg Co.



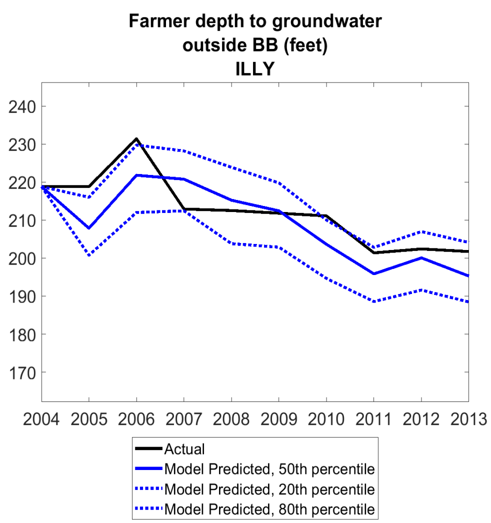

(b) Robustness Check: Riedman



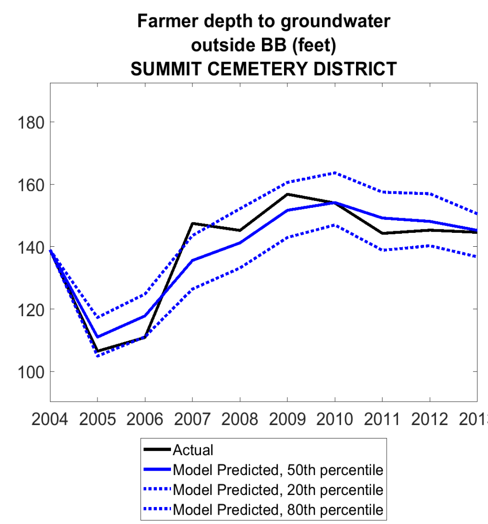

(c) Robustness Check: Hudson




(d) Robustness Check: Dowling

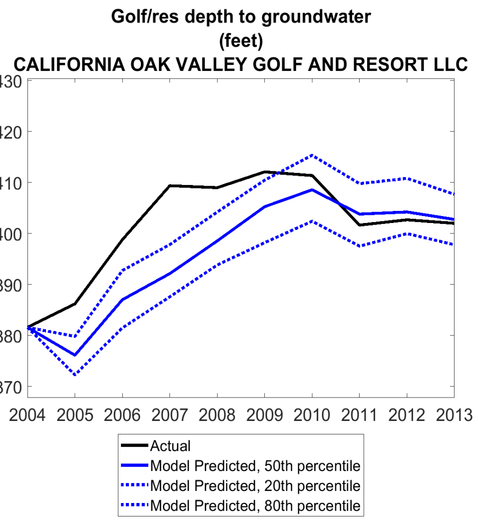



(e) Robustness Check: Illy

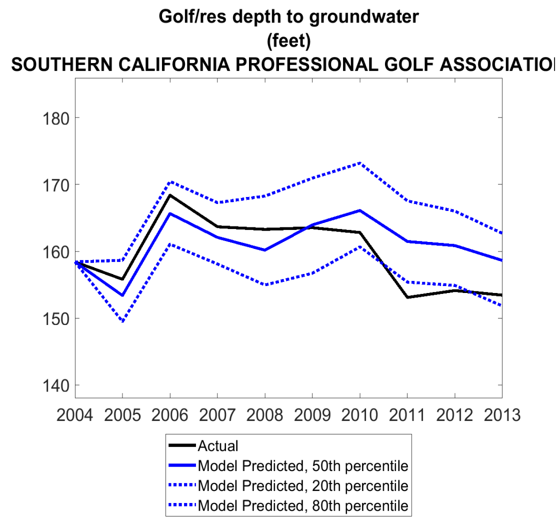



(f) Robustness Check: Summit Cemetery District

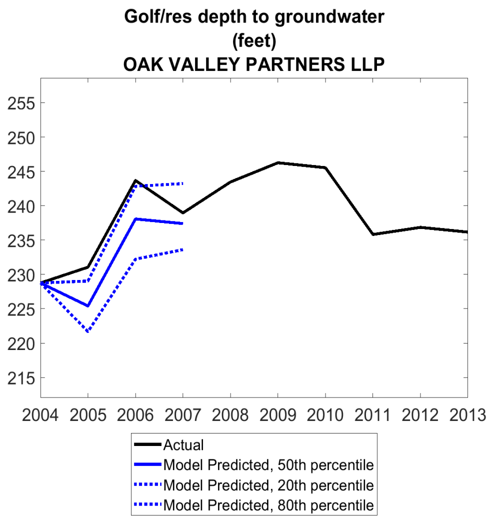
Figure B.12: Robustness Check: Model Fit Comparison: Farmer Depth to Groundwater



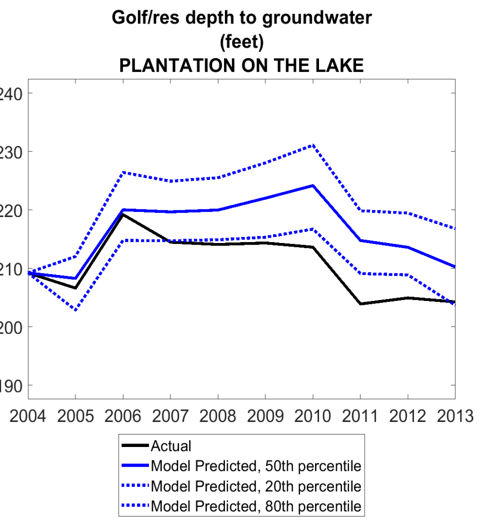

(a) Robustness Check: California Oak Valley Golf and Resort LLC



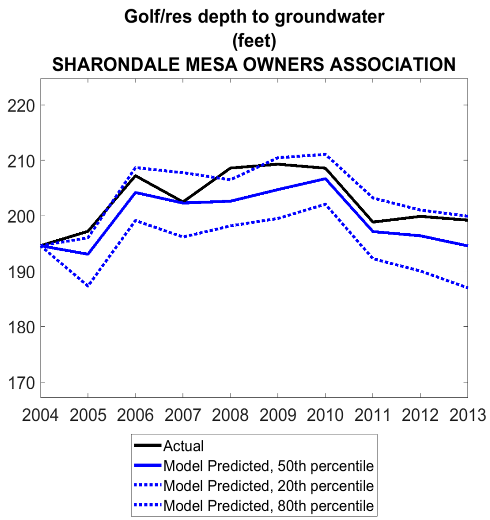

(b) Robustness Check: Southern California PGA




(c) Robustness Check: Oak Valley Partners LLP




(d) Robustness Check: Plantation on the Lake




(e) Robustness Check: Sharondale Mesa Owners Association

Figure B.13: Robustness Check: Model Fit Comparison: Recreational User Depth to Groundwater

Table B.3: Robustness Check: Revenue Parameters

| | Revenue Parameters |
|---|---|
| *Coefficient in Farmer Marginal Revenue on:* | |
| Precipitation (inches) | 29.482 |
| | (18.916) |
| Average crop price (dollars per unit) | -0.156 |
| | (0.364) |
| Has wells inside Beaumont Basin dummy | 92.066* |
| | (35.379) |
| *Coefficient in Recreational User Marginal Revenue on:* | |
| Golf course (dummy) | -15,549.172*** |
| | (2291.254) |
| Golf course (dummy) X Real GDP per capita ($1,000) | 277.18*** |
| | (41.756) |
| Retirement home (dummy) | -0.479 |
| | (2.324) |
| Constant | 53.102*** |
| | (4.939) |
| *Coefficient in Appropriator Marginal Revenue on:* | |
| Full year evapotranspiration (inches) | -12.958** |
| | (4.573) |
| *Weight in Appropriator Per-Period Payoffs on:* | |
| Consumer surplus | 0.867*** |
| | (0.086) |
| Consumer surplus, squared | 0.000000016*** |
| | (0.000) |
| Profits from water sales | 1.000 |
| | (normalization) |

Notes: Per-period payoffs, revenue, and marginal revenue are in dollars. Standard errors are in parentheses. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table B.4: Robustness Check: Cost of Water Extraction and Well Drilling

| | Appropriators | Farmers | Golf Course / Housing Development |
|---|---|---|---|
| *Coefficient in Water Extraction Cost on:* | | | |
| Extraction per well (acre-feet) squared | -0.00205 | 0.273 | 0.005*** |
| | (0.002) | (0.138) | (0.001) |
| *Coefficient in Well Drilling Cost on:* | | | |
| Number of new wells × Depth to groundwater (100 ft) | 26,868.8*** | | |
| | (5,256.1) | | |

Notes: Costs are in dollars. Standard errors are in parentheses. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table B.5: Robustness Check: Marginal Value of Property Rights and Imported Water

| | *Coefficient in Property Right and Imported Water Value on:* | | | | |
|---|---|---|---|---|---|
| | Property Rights Net of Recharge Extraction Ratio | Overlyer Property Rights Extraction Ratio | Artificial Recharge Constant | Filtered Sales Constant | Artificial Recharge X Distance to Recharge Facility |
| Coefficient | 16,643.34 | -1737.36*** | 352.65*** | 367.56*** | 0.017** |
| | (132564.28) | (166.06) | (23.60) | (22.18) | (0.006) |

| | Total Average Effects |
|---|---|
| Property Rights, Appropriators | -0.076 |
| Property Rights, Overlyers | 2.061*** |
| Artificial Recharge | 430.70*** |
| SWP Filtered Sales | 367.56*** |

Notes: Values are in dollars. Standard errors are in parentheses. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table B.6: Robustness Check: Average Annual Welfare, 2004-2013

| | *Average Annual Welfare (dollars)* | | |
|---|---|---|---|
| Player | Actual | Model Predicted | Model Predicted Minus Actual |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | 8.2 million | 9.1 million | 0.9 million * |
| City of Banning | 7.6 million | 8.4 million | 0.8 million *** |
| South Mesa Water Company | 2.5 million | 2.8 million | 0.3 million *** |
| Yucaipa Valley Water District | 13.5 million | 14.9 million | 1.5 million *** |
| **Total appropriators** | **31.7 million** | **35.2 million** | **3.4 million *** ** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 20.6 thousand | 23 thousand | 2.4 thousand |
| Riedman | 6.7 thousand | 6.9 thousand | 0.2 thousand |
| **Total farmers in Beaumont Basin** | **27.3 thousand** | **29.9 thousand** | **2.6 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | 1 thousand | 0 thousand | -1 thousand |
| Illy | 4.5 thousand | 4.4 thousand | -0.1 thousand |
| Summit Cemetery District | 1.4 thousand | -0.7 thousand | -2.1 thousand |
| Hudson | 8.7 thousand | 9.6 thousand | 0.9 thousand |
| **Total farmers outside Beaumont Basin** | **15.6 thousand** | **13.3 thousand** | **-2.3 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | -27.2 thousand | -23.8 thousand | 3.4 thousand |
| Southern California PGA | 27.5 thousand | 18 thousand | -9.5 thousand |
| Oak Valley Partners | 0 thousand | 0.2 thousand | 0.2 thousand |
| Plantation on the Lake | 0.1 thousand | -0.1 thousand | -0.2 thousand |
| Sharondale Mesa Owners Association | -0.2 thousand | -0.2 thousand | 0 thousand |
| **Total recreational users** | **0.2 thousand** | **-5.9 thousand** | **-6.1 thousand** |

Notes: Welfare is the present discounted value of the entire stream of per-period payoffs over the period 2004-2013. Average annual welfare is welfare divided by the number of years. 'Difference from actual' is the difference between model predicted and actual welfare values. Both actual and model predicted welfare are calculated using the parameter estimates from the structural model. Actual welfare is calculated using actual values of actions and states in the data. Model predicted welfare is calculated using model predicted actions and states generated from 100 simulation runs of the open access period. The standard errors for the model predicted welfare values and for the difference between model predicted and actual welfare values are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to the difference between model predicted and actual welfare values denote the significance level of the difference between model predicted and actual average annual welfare. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table B.7: Robustness Check: Model Predicted Average Annual Profits, 2004-2013

| Player | Model Predicted | | |
|---|---|---|---|
| | *Profits (dollars)* | *Revenues (dollars)* | *Costs (dollars)* |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | -1.3 million | 0 million | 1.3 million |
| City of Banning | -0.2 million | 0.2 million | 0.4 million |
| South Mesa Water Company | 0.1 million | 0.2 million | 0.05 million |
| Yucaipa Valley Water District | -1.8 million | -0.4 million | 1.3 million |
| **Total Appropriator** | **-3.1 million** | **0 million** | **3.1 million** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 23.3 thousand | 69.6 thousand | 46.2 thousand |
| Riedman | 7.4 thousand | 30.6 thousand | 23.2 thousand |
| **Total Farmers in Beaumont Basin** | **30.7 thousand** | **100.1 thousand** | **69.5 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | 0 thousand | 4 thousand | 4 thousand |
| Illy | 4.4 thousand | 17.4 thousand | 13 thousand |
| Summit | -0.7 thousand | 4.1 thousand | 4.8 thousand |
| Hudson | 9.6 thousand | 38.6 thousand | 29 thousand |
| **Total Farmers outside Beaumont Basin** | **13.3 thousand** | **64.2 thousand** | **50.9 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | -22.9 thousand | 21.1 thousand | 44 thousand |
| Southern California PGA | 18.6 thousand | 49.1 thousand | 30.5 thousand |
| Oak Valley Partners | 0.5 thousand | 16.9 thousand | 16.4 thousand |
| Plantation on the Lake | 0.6 thousand | 11.5 thousand | 10.9 thousand |
| Sharondale Mesa Owners Association | 0.8 thousand | 6.2 thousand | 5.3 thousand |
| **Total Recreational Users** | **-2.4 thousand** | **104.7 thousand** | **107.1 thousand** |

Notes: Average annual profits, revenues, and costs are the present discounted value of the entire stream over the period 2004-2013 of profits, revenues, and costs, respectively, divided by the number of years. For farmers and recreational users, average annual welfare is equal to average annual profits. For appropriators, profits are the profits from water sales given by the water sale revenues minus extraction costs, while the per-payoffs are a weighted quadratic function of consumer surplus and the profits from water sales. Model predicted profit components are calculated using the parameter estimates from the structural model, and the model predicted actions and states.

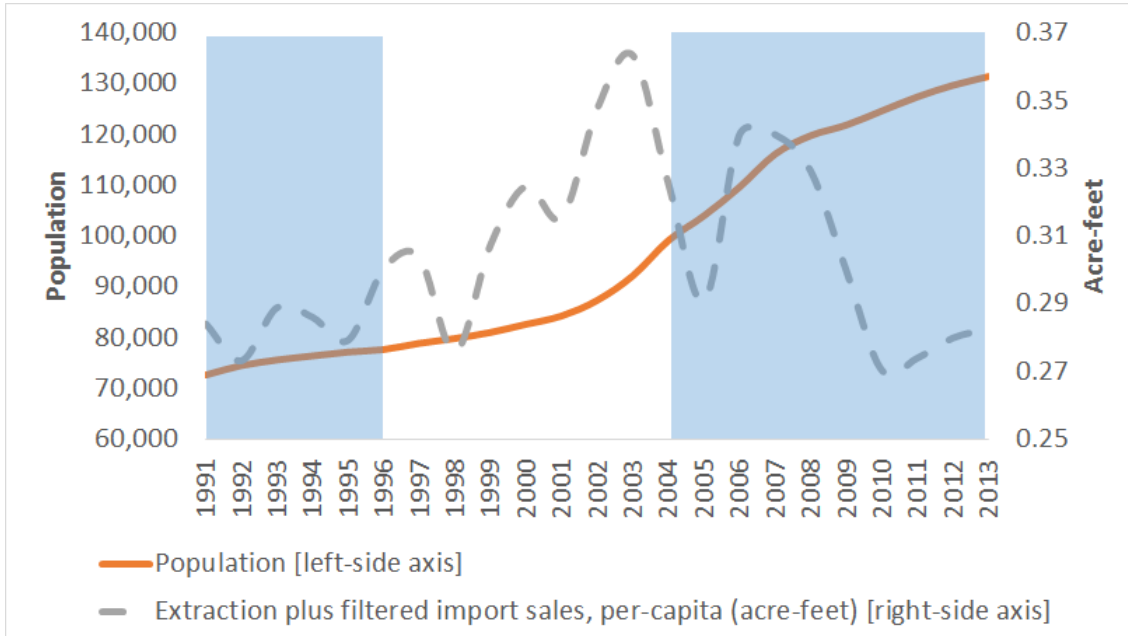



Figure B.14: Robustness Check: Trends in Population and Water Consumption, 1991-2013

Table B.8: Robustness Check: Model Predicted vs. Actual Average Annual Profits, 2004-2013

| Player | Model Predicted Minus Actual Data | | |
|---|---|---|---|
| | *Profits (dollars)* | *Revenues (dollars)* | *Costs (dollars)* |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | -0.1 million | 0 million | 0.1 million |
| City of Banning | -0.1 million | 0 million | 0.1 million |
| South Mesa Water Company | 0 million | 0.1 million | 0.02 million |
| Yucaipa Valley Water District | -0.1 million | 0 million | 0.1 million |
| **Total Appropriator** | **-0.3 million** | **0.1 million** | **0.3 million** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 2.5 thousand | 10.7 thousand | 8.2 thousand |
| Riedman | 0.3 thousand | 4.2 thousand | 3.9 thousand |
| **Total Farmers in Beaumont Basin** | **2.7 thousand** | **14.9 thousand** | **12.1 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | -1 thousand | 0.2 thousand | 1.2 thousand *** |
| Illy | -0.1 thousand | 1.6 thousand | 1.7 thousand ** |
| Summit | -2.1 thousand | 0.8 thousand | 2.8 thousand *** |
| Hudson | 0.9 thousand | 4 thousand | 3.1 thousand * |
| **Total Farmers outside Beaumont Basin** | **-2.3 thousand** | **6.6 thousand** | **8.8 thousand *** ** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | 3.4 thousand | 4.9 thousand | 1.5 thousand |
| Southern California PGA | -9.4 thousand | -6.9 thousand | 2.5 thousand |
| Oak Valley Partners | 0.2 thousand | 2.3 thousand | 2.1 thousand * |
| Plantation on the Lake | -0.1 thousand | 1.1 thousand ** | 1.2 thousand |
| Sharondale Mesa Owners Association | 0.2 thousand | 1 thousand ** | 0.9 thousand |
| **Total Recreational Users** | **-5.7 thousand** | **2.4 thousand** | **8.2 thousand** |

Notes: Average annual profits, revenues, and costs are the present discounted value of the entire stream over the period 2004-2013 of profits, revenues, and costs, respectively, divided by the number of years. For farmers and recreational users, average annual welfare is equal to average annual profits. For appropriators, profits are the profits from water sales given by the water sale revenues minus extraction costs, while the per-payoffs are a weighted quadratic function of consumer surplus and the profits from water sales. Both actual and model predicted profit components are calculated using the parameter estimates from the structural model. Actual profit components are calculated using actual values of actions and states in the data. Model predicted profit components are calculated using model predicted actions and states. Table reports the difference between model predicted and actual values of the respective average annual profit component. Significance stars denote the significance level of the difference between model predicted and actual values of the respective average annual profit component. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table B.9: Robustness Check: Social Welfare, 2004-2013

| | Actual | Model Predicted | Model Predicted Minus Actual |
|---|---|---|---|
| Producer Surplus Components | | | |
| Appropriator profits | -2.8 million | -3.1 million | -0.3 million |
| Farmer profits inside Beaumont Basin | 27.3 thousand | 29.9 thousand | 2.6 thousand |
| Farmer profits outside Beaumont Basin | 15.6 thousand | 13.3 thousand | -2.3 thousand |
| Recreational user profits | 0.2 thousand | -5.9 thousand | -6.1 thousand |
| **Total Producer Surplus** | **-2.77 million** | **-3.03 million** | **-0.26 million** |
| | *Average Annual Consumer Surplus (dollars)* | | |
| Beaumont-Cherry Valley Water District | 7.8 million | 8.7 million | 0.9 million * |
| City of Banning | 7.1 million | 7.9 million | 0.8 million *** |
| South Mesa Water Company | 2.6 million | 2.9 million | 0.3 million *** |
| Yucaipa Valley Water District | 12 million | 13.3 million | 1.3 million *** |
| **Total Consumer Surplus** | **29.5 million** | **32.7 million** | **3.2 million *** ** |
| | *Average Annual Value of Property Rights (dollars)* | | |
| Beaumont-Cherry Valley Water District | 1.9 thousand | 2.1 thousand | 0.2 thousand |
| City of Banning | 0.5 thousand | 0.6 thousand | 0.1 thousand |
| South Mesa Water Company | 0.7 thousand | 0.7 thousand | 0 thousand |
| Yucaipa Valley Water District | 0.7 thousand | 0.8 thousand | 0.1 thousand |
| Farmers inside Beaumont Basin | -0.7 thousand | -0.8 thousand | -0.1 thousand |
| Recreational Users | -3.1 thousand | -3.5 thousand | -0.4 thousand *** |
| **Total Value of Property Rights** | **0 million** | **0 million** | **0 million** |
| | *Average Annual Value of Imported Water (dollars)* | | |
| Beaumont-Cherry Valley Water District | 802.1 thousand | 873.1 thousand | 70.9 thousand |
| City of Banning | 196 thousand | 219.5 thousand | 23.5 thousand |
| South Mesa Water Company | N/A | N/A | N/A |
| Yucaipa Valley Water District | 911.5 thousand | 991 thousand | 79.5 thousand |
| **Total Value of Imported Water** | **1.9 million** | **2.1 million** | **174 thousand** |
| **Social Welfare** | **28.7 million** | **31.8 million** | **3.1 million *** ** |

Notes: Components of social welfare are the present discounted value of the entire stream of per-period payoffs related to each component over the period 2004-2013. Average annual values of these components are equal to the total value of the component divided by the number of years. Producer surplus is equal to the sum of profits from groundwater extraction by each group of players, and the value of holding property rights for appropriators. Consumer surplus is equal to the sum of consumer surplus for each appropriator in the sample and is determined by the residential demand model. It is not weighted by parameters in the payoff function of the appropriator. Social welfare is equal to the sum of producer surplus and consumer surplus. Difference from actual' is the difference between model predicted and actual component values. Actual values are calculated using actual values of actions and states in the data. Model predicted values are calculated using model predicted actions and states generated from 100 simulation runs of the open access period. The standard errors for the difference between model predicted and actual welfare values are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to the difference between model predicted and actual values denote the significance level of the difference between model predicted and actual average annual values. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table B.10: Robustness Check: No Artificial Recharge Counterfactual: Average Annual Welfare, 2004-2013

| Player | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Appropriator Profits | | | |
| Beaumont-Cherry Valley Water District | -1.3 million | 0.8 million *** | 1 million *** |
| City of Banning | -0.2 million | 0.1 million | 0.2 million * |
| South Mesa Water Company | 0 million | 0 million | -0.1 million |
| Yucaipa Valley Water District | -2.5 million | -0.3 million | -0.1 million |
| **Total appropriators** | **-3.9 million** | **0.7 million** | **1.1 million** |
| | | *Average Annual Welfare (dollars)* | |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | 9.2 million | 1 million | 0.1 million |
| City of Banning | 8.4 million | 0.8 million | 0 million |
| South Mesa Water Company | 2.8 million | 0.3 million | 0 million |
| Yucaipa Valley Water District | 14.9 million | 1.5 million | 0 million |
| **Total appropriators** | **35.3 million** | **3.6 million** | **0.1 million** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 24.7 thousand | 4.1 thousand | 1.7 thousand |
| Riedman | 4.3 thousand | -2.3 thousand | -2.5 thousand |
| **Total farmers in Beaumont Basin** | **29 thousand** | **1.8 thousand** | **-0.8 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | 0.1 thousand | -0.9 thousand | 0.1 thousand |
| Illy | 4.4 thousand | -0.1 thousand | 0 thousand |
| Summit Cemetery District | -0.8 thousand | -2.2 thousand | -0.1 thousand |
| Hudson | 9.6 thousand | 1 thousand | 0.1 thousand |
| **Total farmers outside Beaumont Basin** | **13.4 thousand** | **-2.2 thousand** | **0.1 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | -24.1 thousand | 3 thousand | -0.4 thousand |
| Southern California PGA | 18 thousand | -9.4 thousand | 0 thousand |
| Oak Valley Partners | 0.2 thousand | 0.2 thousand | 0 thousand |
| Plantation on the Lake | -0.1 thousand | -0.2 thousand | 0 thousand |
| Sharondale Mesa Owners Association | -0.2 thousand | 0 thousand | 0 thousand |
| **Total recreational users** | **-6.2 thousand** | **-6.4 thousand** | **-0.3 thousand** |

Notes: Welfare is the present discounted value of the entire stream of per-period payoffs over the period 2004-2013. Average annual welfare is welfare divided by the number of years. Counterfactual, actual, and Base scenario welfare are calculated using the parameter estimates from the structural model. Actual welfare is calculated using actual values of actions and states in the data. Counterfactual welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 under the assumption that no artificial recharge takes place. Base scenario welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual welfare values, Base scenario welfare values, the difference between counterfactual and actual welfare values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario welfare values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' welfare values and 'Counterfactual Minus Base Scenario' welfare values denote the significance level of the respective differences. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table B.11: Robustness Check: No Artificial Recharge Counterfactual Social Welfare, 2004-2013

| | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Producer Surplus Components | | | |
| Appropriator profits | -2 million | 0.8 million | 1.1 million |
| Farmer profits inside Beaumont Basin | 29 thousand | 1.8 thousand | -0.8 thousand |
| Farmer profits outside Beaumont Basin | 13.4 thousand | -2.2 thousand | 0.1 thousand |
| Recreational user profits | -6.2 thousand | -6.4 thousand | -0.3 thousand |
| **Total Producer Surplus** | **-1.96 million** | **0.81 million** | **1.07 million** |
| | *Average Annual Consumer Surplus (dollars)* | | |
| Beaumont-Cherry Valley Water District | 8.7 million | 0.9 million *** | 0 million *** |
| City of Banning | 7.9 million | 0.8 million *** | 0 million *** |
| South Mesa Water Company | 2.9 million | 0.3 million *** | 0.1 million *** |
| Yucaipa Valley Water District | 13.3 million | 1.3 million *** | 0 million *** |
| **Total Consumer Surplus** | **32.8 million** | **3.3 million *** ** | **0.1 million *** ** |
| | *Average Annual Value of Property Rights (dollars)* | | |
| Beaumont-Cherry Valley Water District | 2.4 thousand | 0.6 thousand | 0.3 thousand |
| City of Banning | 0.5 thousand | 0 thousand | -0.1 thousand |
| South Mesa Water Company | 0.9 thousand | 0.2 thousand | 0.2 thousand |
| Yucaipa Valley Water District | 0.9 thousand | 0.2 thousand | 0.1 thousand |
| Farmers inside Beaumont Basin | -1.1 thousand | -0.4 thousand *** | -0.3 thousand |
| Recreational Users | -3.5 thousand | -0.4 thousand | 0 thousand |
| **Total Value of Property Rights** | **0 million** | **0 million** | **0 million** |
| | *Average Annual Value of Imported Water (dollars)* | | |
| Beaumont-Cherry Valley Water District | 0 thousand | -802.1 thousand | -0.9 million |
| City of Banning | 0 thousand | -196 thousand | -0.2 million |
| South Mesa Water Company | N/A | N/A | N/A |
| Yucaipa Valley Water District | 991 thousand | 79.5 thousand | 0 million |
| **Total Value of Imported Water** | **1 million** | **-918.6 thousand *** ** | **-1.1 million *** ** |
| **Social Welfare** | **31.9 million** | **3.2 million *** ** | **0.1 million** |

Notes: Components of social welfare are the present discounted value of the entire stream of per-period payoffs related to each component over the period 2004-2013. Average annual values of these components are equal to the total value of the component divided by the number of years. Producer surplus is equal to the sum of profits from groundwater extraction by each group of players, and the value of holding property rights for appropriators. Consumer surplus is equal to the sum of consumer surplus for each appropriator in the sample and is determined by the residential demand model. It is not weighted by parameters in the payoff function of the appropriator. Social welfare is equal to the sum of producer surplus and consumer surplus. Counterfactual, actual, and Base scenario values are calculated using the parameter estimates from the structural model. Actual values are calculated using actual values of actions and states in the data. Counterfactual values are calculated using model predicted actions and states generated from 100 simulation runs of the open access period. Base scenario values is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual values, Base scenario values, the difference between counterfactual and actual values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' values and 'Counterfactual Minus Base Scenario' values denote the significance level of the respective differences. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table B.12: Robustness Check: No Recharge Counterfactual: Simulation Statistics, 2004-2013

| | Appropriator inside Beaumont | Appropriator outside Beaumont | Farmer inside Beaumont | Farmer outside Beaumont | Golf Course / Housing Development | Appropriator Imported Water |
|---|---|---|---|---|---|---|
| | | | *Groundwater Extraction (acre-feet)* | | | *Artificial Recharge (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 3250.02 | 4753.00 | 403.32 | 218.73 | 519.47 | 0.00 |
| Std Dev | 3236.65 | 2699.07 | 332.73 | 218.73 | 434.48 | 0.00 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | -0.021 | 0.074 | 0.612 | 0.002 | 0.000 | -1.000 |
| Std Dev | 0.332 | 0.217 | 0.493 | 0.119 | 0.237 | 0.691 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | -0.041 | 0.080 | 0.482 | 0.001 | 0.001 | -0.994 |
| Std Dev | 0.332 | 0.217 | 0.493 | 0.119 | 0.237 | 0.691 |
| | | | *Depth to Groundwater (feet)* | | | *Filtered Water (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 204.41 | 132.74 | 287.07 | 208.65 | 242.39 | 4729.88 |
| Std Dev | 49.84 | 37.17 | 83.09 | 208.65 | 88.18 | 2440.46 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | 0.090 | 0.005 | 0.004 | 0.005 | -0.002 | -0.005 |
| Std Dev | 0.092 | 0.045 | 0.024 | 0.064 | 0.035 | 0.150 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | 0.088 | -0.001 | 0.011 | 0.002 | 0.001 | 0.000 |
| Std Dev | 0.092 | 0.045 | 0.024 | 0.064 | 0.035 | 0.150 |

Notes: This table compares the counterfactual actions and states with the actual and Base scenario actions and states.

Table B.13: Robustness Check: No Filtered Water Sales Counterfactual: Average Annual Welfare, 2004-2013

| Player | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Appropriator Profits | | | |
| Beaumont-Cherry Valley Water District | -1.3 million | -0.1 million | 0 million |
| City of Banning | -0.2 million | -0.1 million | 0 million |
| South Mesa Water Company | 0 million | 0 million | 0 million |
| Yucaipa Valley Water District | -2.5 million | 1.5 million * | 1.7 million ** |
| **Total appropriators** | **-3.9 million** | **1.4 million** | **1.7 million** |
| | | *Average Annual Welfare (dollars)* | |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | 9.1 million | 0.9 million | 0 million |
| City of Banning | 8.4 million | 0.8 million | 0 million |
| South Mesa Water Company | 2.8 million | 0.3 million | 0 million |
| Yucaipa Valley Water District | 15 million | 1.5 million | 0.1 million |
| **Total appropriators** | **35.3 million** | **3.6 million** | **0.2 million** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 22.4 thousand | 1.8 thousand | -0.6 thousand |
| Riedman | 5 thousand | -1.6 thousand | -1.8 thousand |
| **Total farmers in Beaumont Basin** | **27.4 thousand** | **0.2 thousand** | **-2.5 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | -0.3 thousand | -1.3 thousand | -0.3 thousand |
| Illy | 3.7 thousand | -0.9 thousand | -0.7 thousand |
| Summit Cemetery District | -0.6 thousand | -2 thousand | 0.1 thousand |
| Hudson | 8.9 thousand | 0.2 thousand | -0.7 thousand |
| **Total farmers outside Beaumont Basin** | **11.7 thousand** | **-3.9 thousand** | **-1.6 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | -22.9 thousand | 4.3 thousand | 0.9 thousand |
| Southern California PGA | 17.1 thousand | -10.4 thousand | -0.9 thousand |
| Oak Valley Partners | 0.2 thousand | 0.2 thousand | 0 thousand |
| Plantation on the Lake | -0.2 thousand | -0.3 thousand | -0.1 thousand |
| Sharondale Mesa Owners Association | -0.2 thousand | 0 thousand | 0 thousand |
| **Total recreational users** | **-6 thousand** | **-6.2 thousand** | **-0.1 thousand** |

Notes: Welfare is the present discounted value of the entire stream of per-period payoffs over the period 2004-2013. Average annual welfare is welfare divided by the number of years. Counterfactual, actual, and Base scenario welfare are calculated using the parameter estimates from the structural model. Actual welfare is calculated using actual values of actions and states in the data. Counterfactual welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 under the assumption that no filtered water sales take place. Base scenario welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual welfare values, Base scenario welfare values, the difference between counterfactual and actual welfare values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario welfare values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' welfare values and 'Counterfactual Minus Base Scenario' welfare values denote the significance level of the respective differences. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table B.14: Robustness Check: No Filtered Sales Counterfactual Social Welfare, 2004-2013

| | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Producer Surplus Components | | | |
| Appropriator profits | -1.7 million | 1.1 million | 1.4 million * |
| Farmer profits inside Beaumont Basin | 27.4 thousand | 0.2 thousand | -2.5 thousand |
| Farmer profits outside Beaumont Basin | 11.7 thousand | -3.9 thousand | -1.6 thousand |
| Recreational user profits | -6 thousand | -6.2 thousand | -0.1 thousand |
| **Total Producer Surplus** | **-1.64 million** | **1.13 million** | **1.39 million** |
| | *Average Annual Consumer Surplus (dollars)* | | |
| Beaumont-Cherry Valley Water District | 8.7 million | 0.9 million *** | 0 million |
| City of Banning | 7.9 million | 0.8 million *** | 0 million |
| South Mesa Water Company | 2.8 million | 0.2 million *** | 0 million ** |
| Yucaipa Valley Water District | 12.9 million | 0.9 million *** | -0.3 million *** |
| **Total Consumer Surplus** | **32.4 million** | **2.8 million *** ** | **-0.4 million *** ** |
| | *Average Annual Value of Property Rights (dollars)* | | |
| Beaumont-Cherry Valley Water District | 2.1 thousand | 0.2 thousand | 0 thousand |
| City of Banning | 0.6 thousand | 0.1 thousand | 0 thousand |
| South Mesa Water Company | 0.7 thousand | 0 thousand | 0 thousand |
| Yucaipa Valley Water District | 1.1 thousand | 0.4 thousand | 0.3 thousand |
| Farmers inside Beaumont Basin | -0.8 thousand | -0.1 thousand | 0.1 thousand |
| Recreational Users | -3.5 thousand | -0.4 thousand | 0 thousand |
| **Total Value of Property Rights** | **0 million** | **0 million** | **0 million** |
| | *Average Annual Value of Imported Water (dollars)* | | |
| Beaumont-Cherry Valley Water District | 1076.4 thousand | 274.2 thousand *** | 0.2 million *** |
| City of Banning | 290.8 thousand | 94.8 thousand *** | 0.1 million ** |
| South Mesa Water Company | N/A | N/A | N/A |
| Yucaipa Valley Water District | 0 thousand | -911.5 thousand | -1 million |
| **Total Value of Imported Water** | **1.4 million** | **-542.4 thousand *** ** | **-0.7 million *** ** |
| **Social Welfare** | **32.1 million** | **3.4 million *** ** | **0.3 million *** ** |

Notes: Components of social welfare are the present discounted value of the entire stream of per-period payoffs related to each component over the period 2004-2013. Average annual values of these components are equal to the total value of the component divided by the number of years. Producer surplus is equal to the sum of profits from groundwater extraction by each group of players, and the value of holding property rights for appropriators. Consumer surplus is equal to the sum of consumer surplus for each appropriator in the sample and is determined by the residential demand model. It is not weighted by parameters in the payoff function of the appropriator. Social welfare is equal to the sum of producer surplus and consumer surplus. Counterfactual, actual, and Base scenario values are calculated using the parameter estimates from the structural model. Actual values are calculated using actual values of actions and states in the data. Counterfactual values are calculated using model predicted actions and states generated from 100 simulation runs of the open access period. Base scenario values is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual values, Base scenario values, the difference between counterfactual and actual values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' values and 'Counterfactual Minus Base Scenario' values denote the significance level of the respective differences. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table B.15: Robustness Check: No Filtered Sales Counterfactual: Simulation Statistics, 2004-2013

| | Appropriator inside Beaumont | Appropriator outside Beaumont | Farmer inside Beaumont | Farmer outside Beaumont | Golf Course / Housing Development | Appropriator Imported Water |
|---|---|---|---|---|---|---|
| | | | *Groundwater Extraction (acre-feet)* | | | *Artificial Recharge (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 3648.81 | 4808.09 | 260.60 | 222.01 | 519.61 | 3423.22 |
| Std Dev | 3708.28 | 3439.55 | 373.47 | 222.01 | 434.94 | 2723.46 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | 0.099 | 0.086 | 0.065 | 0.017 | 0.001 | -0.057 |
| Std Dev | 0.264 | 0.311 | 0.489 | 0.121 | 0.242 | 0.401 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | 0.079 | 0.092 | -0.064 | 0.016 | 0.001 | -0.052 |
| Std Dev | 0.264 | 0.311 | 0.489 | 0.121 | 0.242 | 0.401 |
| | | | *Depth to Groundwater (feet)* | | | *Filtered Sales (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 184.29 | 132.95 | 283.19 | 213.22 | 242.83 | 0.00 |
| Std Dev | 49.29 | 37.10 | 85.18 | 213.22 | 87.59 | 0.00 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | -0.017 | 0.007 | -0.010 | 0.027 | 0.000 | -1.000 |
| Std Dev | 0.067 | 0.046 | 0.016 | 0.068 | 0.035 | 0.467 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | -0.020 | 0.001 | -0.002 | 0.024 | 0.003 | -0.995 |
| Std Dev | 0.067 | 0.046 | 0.016 | 0.068 | 0.035 | 0.467 |

Notes: This table compares the counterfactual actions and states with the actual and Base scenario actions and states.

Table B.16: Robustness Check: No Property Rights Trading Counterfactual: Average Annual Welfare, 2004-2013

| Player | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Appropriator Profits | | | |
| Beaumont-Cherry Valley Water District | -1.3 million | -0.3 million | -0.2 million |
| City of Banning | -0.2 million | -0.1 million | 0 million |
| South Mesa Water Company | 0 million | 0 million | 0 million |
| Yucaipa Valley Water District | -2.5 million | -0.2 million | 0 million |
| **Total appropriators** | **-3.9 million** | **-0.5 million** | **-0.2 million** |
| | | *Average Annual Welfare (dollars)* | |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | 9.1 million | 0.9 million | 0 million |
| City of Banning | 8.4 million | 0.9 million | 0 million |
| South Mesa Water Company | 2.8 million | 0.3 million | 0 million |
| Yucaipa Valley Water District | 14.9 million | 1.5 million | 0 million |
| **Total appropriators** | **35.3 million** | **3.5 million** | **0.1 million** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 22.5 thousand | 1.9 thousand | -0.5 thousand |
| Riedman | 6.1 thousand | -0.6 thousand | -0.8 thousand |
| **Total farmers in Beaumont Basin** | **28.6 thousand** | **1.3 thousand** | **-1.3 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | 0 thousand | -1 thousand | 0 thousand |
| Illy | 4.1 thousand | -0.4 thousand | -0.3 thousand |
| Summit Cemetery District | -0.9 thousand | -2.3 thousand | -0.2 thousand |
| Hudson | 9.7 thousand | 1 thousand | 0.1 thousand |
| **Total farmers outside Beaumont Basin** | **12.9 thousand** | **-2.7 thousand** | **-0.4 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | -24.3 thousand | 2.9 thousand | -0.5 thousand |
| Southern California PGA | 19 thousand | -8.5 thousand | 1 thousand |
| Oak Valley Partners | 0.2 thousand | 0.2 thousand | 0 thousand |
| Plantation on the Lake | -0.1 thousand | -0.3 thousand | -0.1 thousand |
| Sharondale Mesa Owners Association | -0.2 thousand | 0 thousand | 0 thousand |
| **Total recreational users** | **-5.5 thousand** | **-5.7 thousand** | **0.4 thousand** |

Notes: Welfare is the present discounted value of the entire stream of per-period payoffs over the period 2004-2013. Average annual welfare is welfare divided by the number of years. Counterfactual, actual, and Base scenario welfare are calculated using the parameter estimates from the structural model. Actual welfare is calculated using actual values of actions and states in the data. Counterfactual welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 under the assumption that no property rights trading takes place. Base scenario welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual welfare values, Base scenario welfare values, the difference between counterfactual and actual welfare values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario welfare values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' welfare values and 'Counterfactual Minus Base Scenario' welfare values denote the significance level of the respective differences. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table B.17: Robustness Check: No Property Rights Trading Counterfactual Social Welfare, 2004-2013

| | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Producer Surplus Components | | | |
| Appropriator profits | -3.5 million | -0.6 million | -0.4 million |
| Farmer profits inside Beaumont Basin | 28.6 thousand | 1.3 thousand | -1.3 thousand |
| Farmer profits outside Beaumont Basin | 12.9 thousand | -2.7 thousand | -0.4 thousand |
| Recreational user profits | -5.5 thousand | -5.7 thousand | 0.4 thousand |
| **Total Producer Surplus** | **-3.41 million** | **-0.65 million** | **-0.39 million** |
| | *Average Annual Consumer Surplus (dollars)* | | |
| Beaumont-Cherry Valley Water District | 8.7 million | 0.9 million *** | 0 million *** |
| City of Banning | 7.9 million | 0.8 million *** | 0 million *** |
| South Mesa Water Company | 2.9 million | 0.3 million *** | 0 million *** |
| Yucaipa Valley Water District | 13.2 million | 1.3 million *** | 0 million *** |
| **Total Consumer Surplus** | **32.7 million** | **3.2 million *** ** | **0 million** |
| | *Average Annual Value of Property Rights (dollars)* | | |
| Beaumont-Cherry Valley Water District | 2 thousand | 0.2 thousand | -0.1 thousand |
| City of Banning | 0.5 thousand | 0.1 thousand | 0 thousand |
| South Mesa Water Company | 0.6 thousand | -0.1 thousand | -0.1 thousand |
| Yucaipa Valley Water District | 0.7 thousand | 0 thousand | -0.1 thousand |
| Farmers inside Beaumont Basin | -0.7 thousand | 0 thousand | 0.1 thousand |
| Recreational Users | -3.5 thousand | -0.4 thousand | 0 thousand |
| **Total Value of Property Rights** | **0 million** | **0 million** | **0 million** |
| | *Average Annual Value of Imported Water (dollars)* | | |
| Beaumont-Cherry Valley Water District | 1243.1 thousand | 441 thousand *** | 0.4 million *** |
| City of Banning | 329 thousand | 133 thousand *** | 0.1 million *** |
| South Mesa Water Company | N/A | N/A | N/A |
| Yucaipa Valley Water District | 1001.9 thousand | 90.4 thousand | 0 million |
| **Total Value of Imported Water** | **2.6 million** | **664.4 thousand *** ** | **0.5 million *** ** |
| **Social Welfare** | **31.9 million** | **3.2 million *** ** | **0.1 million** |

Notes: Components of social welfare are the present discounted value of the entire stream of per-period payoffs related to each component over the period 2004-2013. Average annual values of these components are equal to the total value of the component divided by the number of years. Producer surplus is equal to the sum of profits from groundwater extraction by each group of players, and the value of holding property rights for appropriators. Consumer surplus is equal to the sum of consumer surplus for each appropriator in the sample and is determined by the residential demand model. It is not weighted by parameters in the payoff function of the appropriator. Social welfare is equal to the sum of producer surplus and consumer surplus. Counterfactual, actual, and Base scenario values are calculated using the parameter estimates from the structural model. Actual values are calculated using actual values of actions and states in the data. Counterfactual values are calculated using model predicted actions and states generated from 100 simulation runs of the open access period. Base scenario values is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual values, Base scenario values, the difference between counterfactual and actual values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' values and 'Counterfactual Minus Base Scenario' values denote the significance level of the respective differences. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table B.18: Robustness Check: No Property Rights Trading Counterfactual: Simulation Statistics, 2004-2013

| | Appropriator inside Beaumont | Appropriator outside Beaumont | Farmer inside Beaumont | Farmer outside Beaumont | Golf Course / Housing Development | Appropriator Imported Water |
|---|---|---|---|---|---|---|
| | *Groundwater Extraction (acre-feet)* | | | | | *Artificial Recharge (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 3416.52 | 4331.24 | 239.12 | 218.10 | 518.37 | 3950.38 |
| Std Dev | 3555.34 | 2737.24 | 374.30 | 218.10 | 432.96 | 2714.65 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | 0.029 | -0.021 | -0.023 | -0.001 | -0.002 | 0.088 |
| Std Dev | 0.205 | 0.151 | 0.379 | 0.120 | 0.243 | 0.423 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | 0.009 | -0.015 | -0.152 | -0.002 | -0.001 | 0.094 |
| Std Dev | 0.205 | 0.151 | 0.379 | 0.120 | 0.243 | 0.423 |
| | *Depth to Groundwater (feet)* | | | | | *Filtered Sales (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 181.03 | 132.67 | 282.56 | 207.39 | 241.98 | 4765.54 |
| Std Dev | 48.74 | 37.19 | 85.65 | 207.39 | 87.20 | 2406.59 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | -0.035 | 0.005 | -0.012 | -0.001 | -0.003 | 0.002 |
| Std Dev | 0.058 | 0.044 | 0.016 | 0.061 | 0.035 | 0.150 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | -0.037 | -0.001 | -0.004 | -0.004 | 0.000 | 0.008 |
| Std Dev | 0.058 | 0.044 | 0.016 | 0.061 | 0.035 | 0.150 |

Notes: This table compares the counterfactual actions and states with the actual and Base scenario actions and states.

Table B.19: Robustness Check: No Imported Water Counterfactual: Average Annual Welfare, 2004-2013

| Player | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Appropriator Profits | | | |
| Beaumont-Cherry Valley Water District | -1.3 million | 0.8 million *** | 1 million *** |
| City of Banning | -0.2 million | 0.1 million | 0.2 million * |
| South Mesa Water Company | 0 million | 0 million | -0.1 million |
| Yucaipa Valley Water District | -2.5 million | 1.4 million * | 1.6 million ** |
| **Total appropriators** | **-3.9 million** | **2.4 million *** | **2.7 million** |
| | | *Average Annual Welfare (dollars)* | |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | 9.2 million | 1 million | 0.1 million |
| City of Banning | 8.4 million | 0.8 million | 0 million |
| South Mesa Water Company | 2.8 million | 0.3 million | 0 million |
| Yucaipa Valley Water District | 15 million | 1.6 million | 0.1 million |
| **Total appropriators** | **35.4 million** | **3.7 million** | **0.2 million** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 24.8 thousand | 4.1 thousand | 1.7 thousand |
| Riedman | 4.3 thousand | -2.4 thousand | -2.6 thousand |
| **Total farmers in Beaumont Basin** | **29.1 thousand** | **1.8 thousand** | **-0.8 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | 0.2 thousand | -0.8 thousand | 0.2 thousand |
| Illy | 3.9 thousand | -0.6 thousand | -0.5 thousand |
| Summit Cemetery District | -1 thousand | -2.4 thousand | -0.3 thousand |
| Hudson | 8.8 thousand | 0.1 thousand | -0.8 thousand |
| **Total farmers outside Beaumont Basin** | **11.8 thousand** | **-3.7 thousand** | **-1.5 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | -21.7 thousand | 5.4 thousand | 2.1 thousand |
| Southern California PGA | 19.4 thousand | -8 thousand | 1.4 thousand |
| Oak Valley Partners | 0.2 thousand | 0.2 thousand | 0 thousand |
| Plantation on the Lake | -0.2 thousand | -0.3 thousand | -0.1 thousand |
| Sharondale Mesa Owners Association | -0.2 thousand | 0 thousand | 0 thousand |
| **Total recreational users** | **-2.4 thousand** | **-2.7 thousand** | **3.4 thousand** |

Notes: Welfare is the present discounted value of the entire stream of per-period payoffs over the period 2004-2013. Average annual welfare is welfare divided by the number of years. Counterfactual, actual, and Base scenario welfare are calculated using the parameter estimates from the structural model. Actual welfare is calculated using actual values of actions and states in the data. Counterfactual welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 under the assumption that no imported water takes place. Base scenario welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual welfare values, Base scenario welfare values, the difference between counterfactual and actual welfare values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario welfare values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' welfare values and 'Counterfactual Minus Base Scenario' welfare values denote the significance level of the respective differences. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table B.20: Robustness Check: No Imported Water Counterfactual Social Welfare, 2004-2013

| | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Producer Surplus Components | | | |
| Appropriator profits | -0.5 million | 2.4 million *** | 2.6 million *** |
| Farmer profits inside Beaumont Basin | 29.1 thousand | 1.8 thousand | -0.8 thousand |
| Farmer profits outside Beaumont Basin | 11.8 thousand | -3.7 thousand | -1.5 thousand |
| Recreational user profits | -2.4 thousand | -2.7 thousand | 3.4 thousand |
| **Total Producer Surplus** | **-0.41 million** | **2.35 million** | **2.61 million** |
| | *Average Annual Consumer Surplus (dollars)* | | |
| Beaumont-Cherry Valley Water District | 8.7 million | 0.9 million *** | 0 million *** |
| City of Banning | 7.9 million | 0.8 million *** | 0 million *** |
| South Mesa Water Company | 2.9 million | 0.3 million *** | 0.1 million *** |
| Yucaipa Valley Water District | 13 million | 1 million *** | -0.3 million *** |
| **Total Consumer Surplus** | **32.5 million** | **3 million *** ** | **-0.2 million *** ** |
| | *Average Annual Value of Property Rights (dollars)* | | |
| Beaumont-Cherry Valley Water District | 2.4 thousand | 0.6 thousand | 0.3 thousand |
| City of Banning | 0.5 thousand | 0 thousand | -0.1 thousand |
| South Mesa Water Company | 0.8 thousand | 0.2 thousand | 0.1 thousand |
| Yucaipa Valley Water District | 1.5 thousand | 0.8 thousand | 0.7 thousand |
| Farmers inside Beaumont Basin | -1.1 thousand | -0.4 thousand *** | -0.3 thousand |
| Recreational Users | -3.5 thousand | -0.4 thousand | 0 thousand |
| **Total Value of Property Rights** | **0 million** | **0 million** | **0 million** |
| | *Average Annual Value of Imported Water (dollars)* | | |
| Beaumont-Cherry Valley Water District | 0 thousand | -802.1 thousand | -0.9 million |
| City of Banning | 0 thousand | -196 thousand | -0.2 million |
| South Mesa Water Company | N/A | N/A | N/A |
| Yucaipa Valley Water District | 0 thousand | -911.5 thousand | -1 million |
| **Total Value of Imported Water** | **0 million** | **-1909.6 thousand** | **-2.1 million** |
| **Social Welfare** | **32.1 million** | **3.5 million *** ** | **0.3 million ** ** |

Notes: Components of social welfare are the present discounted value of the entire stream of per-period payoffs related to each component over the period 2004-2013. Average annual values of these components are equal to the total value of the component divided by the number of years. Producer surplus is equal to the sum of profits from groundwater extraction by each group of players, and the value of holding property rights for appropriators. Consumer surplus is equal to the sum of consumer surplus for each appropriator in the sample and is determined by the residential demand model. It is not weighted by parameters in the payoff function of the appropriator. Social welfare is equal to the sum of producer surplus and consumer surplus. Counterfactual, actual, and Base scenario values are calculated using the parameter estimates from the structural model. Actual values are calculated using actual values of actions and states in the data. Counterfactual values are calculated using model predicted actions and states generated from 100 simulation runs of the open access period. Base scenario values is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual values, Base scenario values, the difference between counterfactual and actual values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' values and 'Counterfactual Minus Base Scenario' values denote the significance level of the respective differences. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table B.21: Robustness Check: No Imported Water Counterfactual: Simulation Statistics, 2004-2013

| | Appropriator inside Beaumont | Appropriator outside Beaumont | Farmer inside Beaumont | Farmer outside Beaumont | Golf Course / Housing Development | Appropriator Imported Water |
|---|---|---|---|---|---|---|
| | | | *Groundwater Extraction (acre-feet)* | | | *Artificial Recharge (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 3407.72 | 5306.89 | 406.53 | 222.76 | 517.52 | 0.00 |
| Std Dev | 3168.71 | 3226.90 | 331.03 | 222.76 | 433.93 | 0.00 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | 0.026 | 0.199 | 0.624 | 0.020 | -0.004 | -1.000 |
| Std Dev | 0.373 | 0.298 | 0.503 | 0.121 | 0.241 | 0.691 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | 0.007 | 0.205 | 0.494 | 0.019 | -0.003 | -0.994 |
| Std Dev | 0.373 | 0.298 | 0.503 | 0.121 | 0.241 | 0.691 |
| | | | *Depth to Groundwater (feet)* | | | *Filtered Sales (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 204.07 | 132.43 | 286.85 | 213.54 | 242.28 | 0.00 |
| Std Dev | 50.01 | 37.16 | 83.04 | 213.54 | 87.79 | 0.00 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | 0.088 | 0.003 | 0.003 | 0.029 | -0.002 | -1.000 |
| Std Dev | 0.093 | 0.044 | 0.024 | 0.072 | 0.035 | 0.467 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | 0.086 | -0.003 | 0.011 | 0.026 | 0.001 | -0.995 |
| Std Dev | 0.093 | 0.044 | 0.024 | 0.072 | 0.035 | 0.467 |

Notes: This table compares the counterfactual actions and states with the actual and Base scenario actions and states.

Table B.22: Robustness Check: No Imports or Trading Counterfactual: Average Annual Welfare, 2004-2013

| Player | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Appropriator Profits | | | |
| Beaumont-Cherry Valley Water District | -1.3 million | 0.8 million *** | 1 million *** |
| City of Banning | -0.2 million | 0.1 million | 0.2 million * |
| South Mesa Water Company | 0 million | -0.1 million | -0.1 million |
| Yucaipa Valley Water District | -2.5 million | 1.4 million * | 1.6 million ** |
| **Total appropriators** | **-3.9 million** | **2.3 million *** | **2.7 million** |
| | | *Average Annual Welfare (dollars)* | |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | 9.2 million | 1 million | 0.1 million |
| City of Banning | 8.4 million | 0.8 million | 0 million |
| South Mesa Water Company | 2.8 million | 0.3 million | 0 million |
| Yucaipa Valley Water District | 15 million | 1.6 million | 0.1 million |
| **Total appropriators** | **35.4 million** | **3.6 million** | **0.2 million** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 24.7 thousand | 4.1 thousand | 1.7 thousand |
| Riedman | 4.3 thousand | -2.3 thousand | -2.5 thousand |
| **Total farmers in Beaumont Basin** | **29 thousand** | **1.8 thousand** | **-0.8 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | 0.1 thousand | -0.9 thousand | 0.1 thousand |
| Illy | 4.3 thousand | -0.2 thousand | -0.1 thousand |
| Summit Cemetery District | -0.8 thousand | -2.1 thousand | -0.1 thousand |
| Hudson | 8.9 thousand | 0.2 thousand | -0.7 thousand |
| **Total farmers outside Beaumont Basin** | **12.6 thousand** | **-3 thousand** | **-0.7 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | -24.1 thousand | 3.1 thousand | -0.3 thousand |
| Southern California PGA | 18 thousand | -9.4 thousand | 0 thousand |
| Oak Valley Partners | 0.2 thousand | 0.2 thousand | 0 thousand |
| Plantation on the Lake | -0.1 thousand | -0.2 thousand | 0 thousand |
| Sharondale Mesa Owners Association | -0.2 thousand | 0 thousand | 0 thousand |
| **Total recreational users** | **-6.1 thousand** | **-6.4 thousand** | **-0.3 thousand** |

Notes: Welfare is the present discounted value of the entire stream of per-period payoffs over the period 2004-2013. Average annual welfare is welfare divided by the number of years. Counterfactual, actual, and Base scenario welfare are calculated using the parameter estimates from the structural model. Actual welfare is calculated using actual values of actions and states in the data. Counterfactual welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 under the assumption that no imported water or property rights trading takes place. Base scenario welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual welfare values, Base scenario welfare values, the difference between counterfactual and actual welfare values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario welfare values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' welfare values and 'Counterfactual Minus Base Scenario' welfare values denote the significance level of the respective differences. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table B.23: No Imports or Trading Counterfactual Social Welfare, 2004-2013

| | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Producer Surplus Components | | | |
| Appropriator profits | -0.5 million | 2.3 million *** | 2.6 million *** |
| Farmer profits inside Beaumont Basin | 29 thousand | 1.8 thousand | -0.8 thousand |
| Farmer profits outside Beaumont Basin | 12.6 thousand | -3 thousand | -0.7 thousand |
| Recreational user profits | -6.1 thousand | -6.4 thousand | -0.3 thousand |
| **Total Producer Surplus** | **-0.45 million** | **2.32 million** | **2.58 million** |
| | *Average Annual Consumer Surplus (dollars)* | | |
| Beaumont-Cherry Valley Water District | 8.7 million | 0.9 million *** | 0 million *** |
| City of Banning | 7.9 million | 0.8 million *** | 0 million *** |
| South Mesa Water Company | 2.9 million | 0.3 million *** | 0.1 million *** |
| Yucaipa Valley Water District | 13 million | 1 million *** | -0.3 million *** |
| **Total Consumer Surplus** | **32.6 million** | **3 million *** ** | **-0.2 million *** ** |
| | *Average Annual Value of Property Rights (dollars)* | | |
| Beaumont-Cherry Valley Water District | 2.5 thousand | 0.6 thousand | 0.4 thousand |
| City of Banning | 0.5 thousand | 0 thousand | -0.1 thousand |
| South Mesa Water Company | 0.7 thousand | 0 thousand | 0 thousand |
| Yucaipa Valley Water District | 1.4 thousand | 0.7 thousand | 0.7 thousand |
| Farmers inside Beaumont Basin | -1.1 thousand | -0.4 thousand *** | -0.3 thousand |
| Recreational Users | -3.5 thousand | -0.4 thousand | 0 thousand |
| **Total Value of Property Rights** | **0 million** | **0 million** | **0 million** |
| | *Average Annual Value of Imported Water (dollars)* | | |
| Beaumont-Cherry Valley Water District | 0 thousand | -802.1 thousand | -0.9 million |
| City of Banning | 0 thousand | -196 thousand | -0.2 million |
| South Mesa Water Company | N/A | N/A | N/A |
| Yucaipa Valley Water District | 0 thousand | -911.5 thousand | -1 million |
| **Total Value of Imported Water** | **0 million** | **-1909.6 thousand** | **-2.1 million** |
| **Social Welfare** | **32.1 million** | **3.4 million *** ** | **0.3 million ** ** |

Notes: Components of social welfare are the present discounted value of the entire stream of per-period payoffs related to each component over the period 2004-2013. Average annual values of these components are equal to the total value of the component divided by the number of years. Producer surplus is equal to the sum of profits from groundwater extraction by each group of players, and the value of holding property rights for appropriators. Consumer surplus is equal to the sum of consumer surplus for each appropriator in the sample and is determined by the residential demand model. It is not weighted by parameters in the payoff function of the appropriator. Social welfare is equal to the sum of producer surplus and consumer surplus. Counterfactual, actual, and Base scenario values are calculated using the parameter estimates from the structural model. Actual values are calculated using actual values of actions and states in the data. Counterfactual values are calculated using model predicted actions and states generated from 100 simulation runs of the open access period. Base scenario values is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual values, Base scenario values, the difference between counterfactual and actual values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' values and 'Counterfactual Minus Base Scenario' values denote the significance level of the respective differences. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table B.24: No Imports or Trading Counterfactual: Simulation Statistics, 2004-2013

| | Appropriator inside Beaumont | Appropriator outside Beaumont | Farmer inside Beaumont | Farmer outside Beaumont | Golf Course / Housing Development | Appropriator Imported Water |
|---|---|---|---|---|---|---|
| | | | *Groundwater Extraction (acre-feet)* | | | *Artificial Recharge (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 3270.09 | 5453.35 | 403.33 | 222.16 | 519.31 | 0.00 |
| Std Dev | 2869.46 | 3175.66 | 332.73 | 222.16 | 434.44 | 0.00 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | -0.015 | 0.232 | 0.612 | 0.017 | 0.000 | -1.000 |
| Std Dev | 0.432 | 0.317 | 0.493 | 0.119 | 0.237 | 0.691 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | -0.035 | 0.238 | 0.482 | 0.016 | 0.001 | -0.994 |
| Std Dev | 0.432 | 0.317 | 0.493 | 0.119 | 0.237 | 0.691 |
| | | | *Depth to Groundwater (feet)* | | | *Filtered Sales (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 204.41 | 132.74 | 287.07 | 213.43 | 242.31 | 0.00 |
| Std Dev | 49.84 | 37.17 | 83.09 | 213.43 | 88.03 | 0.00 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | 0.090 | 0.005 | 0.004 | 0.028 | -0.002 | -1.000 |
| Std Dev | 0.092 | 0.045 | 0.024 | 0.070 | 0.035 | 0.467 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | 0.088 | -0.001 | 0.011 | 0.025 | 0.001 | -0.995 |
| Std Dev | 0.092 | 0.045 | 0.024 | 0.070 | 0.035 | 0.467 |

Notes: This table compares the counterfactual actions and states with the actual and Base scenario actions and states.

Table B.25: Robustness Check: Equal Initial Property Right Allocation Counterfactual: Average Annual Welfare, 2004-2013

| Player | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Appropriator Profits | | | |
| Beaumont-Cherry Valley Water District | -1.3 million | -0.2 million | 0 million |
| City of Banning | -0.2 million | 0 million | 0.1 million |
| South Mesa Water Company | 0 million | -0.1 million | -0.2 million |
| Yucaipa Valley Water District | -2.5 million | -0.3 million | -0.1 million |
| **Total appropriators** | **-3.9 million** | **-0.6 million** | **-0.3 million** |
| | | *Average Annual Welfare (dollars)* | |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | 9.1 million | 0.9 million | 0 million |
| City of Banning | 8.4 million | 0.8 million | 0 million |
| South Mesa Water Company | 2.8 million | 0.2 million | 0 million |
| Yucaipa Valley Water District | 14.9 million | 1.4 million | 0 million |
| **Total appropriators** | **35.2 million** | **3.5 million** | **0 million** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 22.6 thousand | 2 thousand | -0.4 thousand |
| Riedman | 5.7 thousand | -1 thousand | -1.2 thousand |
| **Total farmers in Beaumont Basin** | **28.3 thousand** | **1 thousand** | **-1.6 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | -0.2 thousand | -1.2 thousand | -0.2 thousand |
| Illy | 4.2 thousand | -0.3 thousand | -0.2 thousand |
| Summit Cemetery District | -0.5 thousand | -1.9 thousand | 0.2 thousand |
| Hudson | 9.8 thousand | 1.1 thousand | 0.2 thousand |
| **Total farmers outside Beaumont Basin** | **13.2 thousand** | **-2.3 thousand** | **-0.1 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | -21.8 thousand | 5.4 thousand | 2 thousand |
| Southern California PGA | 18 thousand | -9.5 thousand | 0 thousand |
| Oak Valley Partners | 0.2 thousand | 0.2 thousand | 0 thousand |
| Plantation on the Lake | -0.1 thousand | -0.2 thousand | 0 thousand |
| Sharondale Mesa Owners Association | -0.2 thousand | 0 thousand | 0 thousand |
| **Total recreational users** | **-3.9 thousand** | **-4.2 thousand** | **1.9 thousand** |

Notes: Welfare is the present discounted value of the entire stream of per-period payoffs over the period 2004-2013. Average annual welfare is welfare divided by the number of years. Counterfactual, actual, and Base scenario welfare are calculated using the parameter estimates from the structural model. Actual welfare is calculated using actual values of actions and states in the data. Counterfactual welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 under the assumption of equal initial property rights allocations. Base scenario welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual welfare values, Base scenario welfare values, the difference between counterfactual and actual welfare values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario welfare values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' welfare values and 'Counterfactual Minus Base Scenario' welfare values denote the significance level of the respective differences. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table B.26: Robustness Check: Equal Initial Property Right Allocation Counterfactual Social Welfare, 2004-2013

| | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Producer Surplus Components | | | |
| Appropriator profits | -3.6 million | -0.7 million | -0.5 million |
| Farmer profits inside Beaumont Basin | 28.3 thousand | 1 thousand | -1.6 thousand |
| Farmer profits outside Beaumont Basin | 13.2 thousand | -2.3 thousand | -0.1 thousand |
| Recreational user profits | -3.9 thousand | -4.2 thousand | 1.9 thousand |
| **Total Producer Surplus** | **-3.51 million** | **-0.75 million** | **-0.49 million** |
| | *Average Annual Consumer Surplus (dollars)* | | |
| Beaumont-Cherry Valley Water District | 8.7 million | 0.9 million *** | 0 million |
| City of Banning | 7.9 million | 0.8 million *** | 0 million *** |
| South Mesa Water Company | 3 million | 0.4 million *** | 0.1 million *** |
| Yucaipa Valley Water District | 13.3 million | 1.4 million *** | 0.1 million *** |
| **Total Consumer Surplus** | **32.9 million** | **3.4 million *** ** | **0.2 million *** ** |
| | *Average Annual Value of Property Rights (dollars)* | | |
| Beaumont-Cherry Valley Water District | 1.8 thousand | 0 thousand | -0.3 thousand |
| City of Banning | 0.4 thousand | -0.1 thousand | -0.1 thousand |
| South Mesa Water Company | 0.5 thousand | -0.1 thousand | -0.2 thousand |
| Yucaipa Valley Water District | 1 thousand | 0.3 thousand | 0.2 thousand |
| Farmers inside Beaumont Basin | -0.7 thousand | -0.1 thousand | 0.1 thousand |
| Recreational Users | -3.5 thousand | -0.4 thousand | 0 thousand |
| **Total Value of Property Rights** | **0 million** | **0 million** | **0 million** |
| | *Average Annual Value of Imported Water (dollars)* | | |
| Beaumont-Cherry Valley Water District | 1127.2 thousand | 325.1 thousand *** | 0.3 million *** |
| City of Banning | 307.2 thousand | 111.3 thousand *** | 0.1 million *** |
| South Mesa Water Company | N/A | N/A | N/A |
| Yucaipa Valley Water District | 996.4 thousand | 85 thousand | 0 million |
| **Total Value of Imported Water** | **2.4 million** | **521.3 thousand** | **0.3 million** |
| **Social Welfare** | **31.8 million** | **3.1 million *** ** | **0 million** |

Notes: Components of social welfare are the present discounted value of the entire stream of per-period payoffs related to each component over the period 2004-2013. Average annual values of these components are equal to the total value of the component divided by the number of years. Producer surplus is equal to the sum of profits from groundwater extraction by each group of players, and the value of holding property rights for appropriators. Consumer surplus is equal to the sum of consumer surplus for each appropriator in the sample and is determined by the residential demand model. It is not weighted by parameters in the payoff function of the appropriator. Social welfare is equal to the sum of producer surplus and consumer surplus. Counterfactual, actual, and Base scenario values are calculated using the parameter estimates from the structural model. Actual values are calculated using actual values of actions and states in the data. Counterfactual values are calculated using model predicted actions and states generated from 100 simulation runs of the open access period. Base scenario values is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual values, Base scenario values, the difference between counterfactual and actual values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' values and 'Counterfactual Minus Base Scenario' values denote the significance level of the respective differences. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table B.27: Robustness Check: Equal Initial Property Right Allocation: Simulation Statistics, 2004-2013

| | Appropriator inside Beaumont | Appropriator outside Beaumont | Farmer inside Beaumont | Farmer outside Beaumont | Golf Course / Housing Development | Appropriator Imported Water |
|---|---|---|---|---|---|---|
| | | | *Groundwater Extraction (acre-feet)* | | | *Artificial Recharge (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 3146.12 | 4695.72 | 254.77 | 218.57 | 519.08 | 3573.39 |
| Std Dev | 2562.41 | 2311.38 | 371.26 | 218.57 | 435.49 | 2556.64 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | -0.052 | 0.061 | 0.042 | 0.001 | -0.001 | -0.016 |
| Std Dev | 0.487 | 0.274 | 0.447 | 0.119 | 0.240 | 0.344 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | -0.072 | 0.067 | -0.088 | 0.000 | 0.000 | -0.010 |
| Std Dev | 0.487 | 0.274 | 0.447 | 0.119 | 0.240 | 0.344 |
| | | | *Depth to Groundwater (feet)* | | | *Filtered Sales (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 183.60 | 132.71 | 282.94 | 208.02 | 241.77 | 4745.30 |
| Std Dev | 49.11 | 37.15 | 85.08 | 208.02 | 85.72 | 2420.22 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | -0.021 | 0.005 | -0.011 | 0.002 | -0.004 | -0.002 |
| Std Dev | 0.063 | 0.044 | 0.016 | 0.061 | 0.039 | 0.153 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | -0.023 | -0.001 | -0.003 | -0.001 | -0.001 | 0.003 |
| Std Dev | 0.063 | 0.044 | 0.016 | 0.061 | 0.039 | 0.153 |

Notes: This table compares the counterfactual actions and states with the actual and Base scenario actions and states.

Table B.28: Robustness Check: No Property Right to Recharged Water Counterfactual: Average Annual Welfare, 2004-2013

| Player | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Appropriator Profits | | | |
| Beaumont-Cherry Valley Water District | -1.3 million | -0.1 million | 0 million |
| City of Banning | -0.2 million | 0 million | 0 million |
| South Mesa Water Company | 0 million | 0 million | 0 million |
| Yucaipa Valley Water District | -2.5 million | -0.2 million | 0 million |
| **Total appropriators** | **-3.9 million** | **-0.3 million** | **0 million** |
| | | *Average Annual Welfare (dollars)* | |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | 9.1 million | 0.9 million | 0 million |
| City of Banning | 8.4 million | 0.8 million | 0 million |
| South Mesa Water Company | 2.8 million | 0.3 million | 0 million |
| Yucaipa Valley Water District | 14.9 million | 1.5 million | 0 million |
| **Total appropriators** | **35.3 million** | **3.5 million** | **0.1 million** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 22.4 thousand | 1.8 thousand | -0.6 thousand |
| Riedman | 5.4 thousand | -1.2 thousand | -1.4 thousand |
| **Total farmers in Beaumont Basin** | **27.8 thousand** | **0.5 thousand** | **-2.1 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | -0.1 thousand | -1.1 thousand | -0.1 thousand |
| Illy | 4.4 thousand | -0.1 thousand | 0 thousand |
| Summit Cemetery District | -0.3 thousand | -1.7 thousand | 0.4 thousand |
| Hudson | 9.8 thousand | 1.1 thousand | 0.2 thousand |
| **Total farmers outside Beaumont Basin** | **13.9 thousand** | **-1.7 thousand** | **0.6 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | -23.2 thousand | 3.9 thousand | 0.6 thousand |
| Southern California PGA | 18.6 thousand | -8.9 thousand | 0.6 thousand |
| Oak Valley Partners | 0.2 thousand | 0.2 thousand | 0 thousand |
| Plantation on the Lake | -0.1 thousand | -0.2 thousand | 0 thousand |
| Sharondale Mesa Owners Association | -0.2 thousand | 0 thousand | 0 thousand |
| **Total recreational users** | **-4.7 thousand** | **-5 thousand** | **1.1 thousand** |

Notes: Welfare is the present discounted value of the entire stream of per-period payoffs over the period 2004-2013. Average annual welfare is welfare divided by the number of years. Counterfactual, actual, and Base scenario welfare are calculated using the parameter estimates from the structural model. Actual welfare is calculated using actual values of actions and states in the data. Counterfactual welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 under the assumption of no property right to recharged water. Base scenario welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual welfare values, Base scenario welfare values, the difference between counterfactual and actual welfare values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario welfare values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' welfare values and 'Counterfactual Minus Base Scenario' welfare values denote the significance level of the respective differences. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table B.29: Robustness Check: No Property Right to Recharged Water Counterfactual Social Welfare, 2004-2013

| | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Producer Surplus Components | | | |
| Appropriator profits | -3.2 million | -0.4 million | -0.2 million |
| Farmer profits inside Beaumont Basin | 27.8 thousand | 0.5 thousand | -2.1 thousand |
| Farmer profits outside Beaumont Basin | 13.9 thousand | -1.7 thousand | 0.6 thousand |
| Recreational user profits | -4.7 thousand | -5 thousand | 1.1 thousand |
| **Total Producer Surplus** | **-3.18 million** | **-0.41 million** | **-0.15 million** |
| | *Average Annual Consumer Surplus (dollars)* | | |
| Beaumont-Cherry Valley Water District | 8.7 million | 0.9 million *** | 0 million *** |
| City of Banning | 7.9 million | 0.8 million *** | 0 million *** |
| South Mesa Water Company | 2.8 million | 0.2 million *** | 0 million *** |
| Yucaipa Valley Water District | 13.3 million | 1.3 million *** | 0 million |
| **Total Consumer Surplus** | **32.6 million** | **3.1 million *** ** | **-0.1 million *** ** |
| | *Average Annual Value of Property Rights (dollars)* | | |
| Beaumont-Cherry Valley Water District | 2.1 thousand | 0.3 thousand | 0 thousand |
| City of Banning | 0.5 thousand | 0 thousand | 0 thousand |
| South Mesa Water Company | 0.6 thousand | 0 thousand | -0.1 thousand |
| Yucaipa Valley Water District | 0.7 thousand | 0 thousand | -0.1 thousand |
| Farmers inside Beaumont Basin | -0.7 thousand | -0.1 thousand | 0.1 thousand |
| Recreational Users | -3.5 thousand | -0.4 thousand | 0 thousand |
| **Total Value of Property Rights** | **0 million** | **0 million** | **0 million** |
| | *Average Annual Value of Imported Water (dollars)* | | |
| Beaumont-Cherry Valley Water District | 1086.9 thousand | 284.8 thousand *** | 0.2 million *** |
| City of Banning | 295.1 thousand | 99.1 thousand *** | 0.1 million ** |
| South Mesa Water Company | N/A | N/A | N/A |
| Yucaipa Valley Water District | 1000.7 thousand | 89.2 thousand | 0 million |
| **Total Value of Imported Water** | **2.4 million** | **473.1 thousand** | **0.3 million** |
| **Social Welfare** | **31.9 million** | **3.2 million *** ** | **0.1 million** |

Notes: Components of social welfare are the present discounted value of the entire stream of per-period payoffs related to each component over the period 2004-2013. Average annual values of these components are equal to the total value of the component divided by the number of years. Producer surplus is equal to the sum of profits from groundwater extraction by each group of players, and the value of holding property rights for appropriators. Consumer surplus is equal to the sum of consumer surplus for each appropriator in the sample and is determined by the residential demand model. It is not weighted by parameters in the payoff function of the appropriator. Social welfare is equal to the sum of producer surplus and consumer surplus. Counterfactual, actual, and Base scenario values are calculated using the parameter estimates from the structural model. Actual values are calculated using actual values of actions and states in the data. Counterfactual values are calculated using model predicted actions and states generated from 100 simulation runs of the open access period. Base scenario values is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual values, Base scenario values, the difference between counterfactual and actual values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' values and 'Counterfactual Minus Base Scenario' values denote the significance level of the respective differences. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table B.30: Robustness Check: No Property Right to Recharged Water Counterfactual: Simulation Statistics, 2004-2013

| | Appropriator inside Beaumont | Appropriator outside Beaumont | Farmer inside Beaumont | Farmer outside Beaumont | Golf Course / Housing Development | Appropriator Imported Water |
|---|---|---|---|---|---|---|
| | *Groundwater Extraction (acre-feet)* | | | | | *Artificial Recharge (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 2883.77 | 4733.97 | 257.51 | 217.51 | 516.92 | 3496.15 |
| Std Dev | 2893.43 | 2599.63 | 372.90 | 217.51 | 435.89 | 2641.22 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | -0.131 | 0.069 | 0.053 | -0.004 | -0.005 | -0.037 |
| Std Dev | 0.404 | 0.258 | 0.478 | 0.118 | 0.240 | 0.382 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | -0.151 | 0.075 | -0.077 | -0.005 | -0.004 | -0.032 |
| Std Dev | 0.404 | 0.258 | 0.478 | 0.118 | 0.240 | 0.382 |
| | *Depth to Groundwater (feet)* | | | | | *Filtered Sales (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 183.87 | 132.83 | 283.19 | 207.67 | 241.93 | 4756.95 |
| Std Dev | 49.03 | 37.28 | 84.91 | 207.67 | 86.64 | 2408.19 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | -0.020 | 0.006 | -0.010 | 0.000 | -0.004 | 0.001 |
| Std Dev | 0.065 | 0.044 | 0.017 | 0.062 | 0.036 | 0.153 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | -0.022 | 0.000 | -0.002 | -0.002 | -0.001 | 0.006 |
| Std Dev | 0.065 | 0.044 | 0.017 | 0.062 | 0.036 | 0.153 |

Notes: This table compares the counterfactual actions and states with the actual and Base scenario actions and states.

Table B.31: Robustness Check: Revised Safe Yield Counterfactual: Average Annual Welfare, 2004-2013

| Player | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Appropriator Profits | | | |
| Beaumont-Cherry Valley Water District | -1.3 million | -0.1 million | 0 million |
| City of Banning | -0.2 million | 0 million | 0 million |
| South Mesa Water Company | 0 million | 0 million | 0 million |
| Yucaipa Valley Water District | -2.5 million | -0.2 million | 0 million |
| **Total appropriators** | **-3.9 million** | **-0.3 million** | **0.1 million** |
| | | *Average Annual Welfare (dollars)* | |
| Appropriators | | | |
| Beaumont-Cherry Valley Water District | 9.1 million | 0.9 million | 0 million |
| City of Banning | 8.4 million | 0.8 million | 0 million |
| South Mesa Water Company | 2.8 million | 0.3 million | 0 million |
| Yucaipa Valley Water District | 14.9 million | 1.5 million | 0 million |
| **Total appropriators** | **35.3 million** | **3.5 million** | **0.1 million** |
| Farmers in Beaumont Basin | | | |
| Sunny-Cal Egg | 15.6 thousand | -5 thousand | -7.4 thousand |
| Riedman | 4.9 thousand | -1.8 thousand | -2 thousand |
| **Total farmers in Beaumont Basin** | **20.5 thousand** | **-6.8 thousand** | **-9.4 thousand** |
| Farmers outside Beaumont Basin | | | |
| Dowling | -0.1 thousand | -1.1 thousand | -0.1 thousand |
| Illy | 4.1 thousand | -0.4 thousand | -0.3 thousand |
| Summit Cemetery District | -0.7 thousand | -2 thousand | 0 thousand |
| Hudson | 9.7 thousand | 1 thousand | 0.1 thousand |
| **Total farmers outside Beaumont Basin** | **13.1 thousand** | **-2.4 thousand** | **-0.2 thousand** |
| Recreational Users | | | |
| California Oak Valley Golf and Resort LLC | -19.3 thousand | 7.8 thousand | 4.4 thousand |
| Southern California PGA | 16.1 thousand | -11.3 thousand | -1.9 thousand |
| Oak Valley Partners | 0.2 thousand | 0.2 thousand | 0 thousand |
| Plantation on the Lake | -0.3 thousand | -0.4 thousand | -0.2 thousand |
| Sharondale Mesa Owners Association | -0.5 thousand | -0.3 thousand | -0.3 thousand |
| **Total recreational users** | **-3.7 thousand** | **-4 thousand** | **2.1 thousand** |

Notes: Welfare is the present discounted value of the entire stream of per-period payoffs over the period 2004-2013. Average annual welfare is welfare divided by the number of years. Counterfactual, actual, and Base scenario welfare are calculated using the parameter estimates from the structural model. Actual welfare is calculated using actual values of actions and states in the data. Counterfactual welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 under the assumption of revised safe yield. Base scenario welfare is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual welfare values, Base scenario welfare values, the difference between counterfactual and actual welfare values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario welfare values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' welfare values and 'Counterfactual Minus Base Scenario' welfare values denote the significance level of the respective differences. Significance codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table B.32: Robustness Check: Revised Safe Yield Counterfactual Social Welfare, 2004-2013

| | Counterfactual | Counterfactual Minus Actual | Counterfactual Minus Base Scenario |
|---|---|---|---|
| Producer Surplus Components | | | |
| Appropriator profits | -3.2 million | -0.4 million | -0.2 million |
| Farmer profits inside Beaumont Basin | 20.5 thousand | -6.8 thousand | -9.4 thousand |
| Farmer profits outside Beaumont Basin | 13.1 thousand | -2.4 thousand | -0.2 thousand |
| Recreational user profits | -3.7 thousand | -4 thousand | 2.1 thousand |
| **Total Producer Surplus** | **-3.19 million** | **-0.42 million** | **-0.16 million** |
| | *Average Annual Consumer Surplus (dollars)* | | |
| Beaumont-Cherry Valley Water District | 8.7 million | 0.9 million *** | 0 million ** |
| City of Banning | 7.9 million | 0.8 million *** | 0 million *** |
| South Mesa Water Company | 2.8 million | 0.2 million *** | 0 million *** |
| Yucaipa Valley Water District | 13.2 million | 1.3 million *** | 0 million *** |
| **Total Consumer Surplus** | **32.7 million** | **3.1 million *** ** | **-0.1 million *** ** |
| | *Average Annual Value of Property Rights (dollars)* | | |
| Beaumont-Cherry Valley Water District | 2.1 thousand | 0.2 thousand | 0 thousand |
| City of Banning | 0.5 thousand | 0.1 thousand | 0 thousand |
| South Mesa Water Company | 0.7 thousand | 0 thousand | 0 thousand |
| Yucaipa Valley Water District | 0.7 thousand | 0 thousand | -0.1 thousand |
| Farmers inside Beaumont Basin | -0.4 thousand | 0.3 thousand *** | 0.4 thousand |
| Recreational Users | -4 thousand | -0.9 thousand * | -0.5 thousand |
| **Total Value of Property Rights** | **0 million** | **0 million** | **0 million** |
| | *Average Annual Value of Imported Water (dollars)* | | |
| Beaumont-Cherry Valley Water District | 1078.3 thousand | 276.2 thousand *** | 0.2 million *** |
| City of Banning | 304.2 thousand | 108.2 thousand *** | 0.1 million *** |
| South Mesa Water Company | N/A | N/A | N/A |
| Yucaipa Valley Water District | 998 thousand | 86.5 thousand | 0 million |
| **Total Value of Imported Water** | **2.4 million** | **470.9 thousand** | **0.3 million** |
| **Social Welfare** | **31.8 million** | **3.2 million *** ** | **0.1 million** |

Notes: Components of social welfare are the present discounted value of the entire stream of per-period payoffs related to each component over the period 2004-2013. Average annual values of these components are equal to the total value of the component divided by the number of years. Producer surplus is equal to the sum of profits from groundwater extraction by each group of players, and the value of holding property rights for appropriators. Consumer surplus is equal to the sum of consumer surplus for each appropriator in the sample and is determined by the residential demand model. It is not weighted by parameters in the payoff function of the appropriator. Social welfare is equal to the sum of producer surplus and consumer surplus. Counterfactual, actual, and Base scenario values are calculated using the parameter estimates from the structural model. Actual values are calculated using actual values of actions and states in the data. Counterfactual values are calculated using model predicted actions and states generated from 100 simulation runs of the open access period. Base scenario values is calculated using model predicted actions and states generated from 100 simulation runs of the period 2004-2013 in the absence of any counterfactual change. The standard errors for the counterfactual values, Base scenario values, the difference between counterfactual and actual values ('Counterfactual Minus Actual'), and the difference between counterfactual and Base scenario values ('Counterfactual Minus Base Scenario') are calculated using the parameter estimates from each of 100 bootstrap samples. Significance stars next to 'Counterfactual Minus Actual' values and 'Counterfactual Minus Base Scenario' values denote the significance level of the respective differences. Significance codes: *** p<0.001, ** p<0.01, * p<0.05

Table B.33: Robustness Check: Revised Safe Yield Counterfactual: Simulation Statistics, 2004-2013

| | Appropriator inside Beaumont | Appropriator outside Beaumont | Farmer inside Beaumont | Farmer outside Beaumont | Golf Course / Housing Development | Appropriator Imported Water |
|---|---|---|---|---|---|---|
| | | | *Groundwater Extraction (acre-feet)* | | | *Artificial Recharge (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 3357.82 | 4336.01 | 102.05 | 217.85 | 454.47 | 3476.77 |
| Std Dev | 3647.45 | 2779.09 | 182.99 | 217.85 | 387.63 | 2690.07 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | 0.011 | -0.020 | -0.583 | -0.002 | -0.125 | -0.043 |
| Std Dev | 0.242 | 0.161 | 0.916 | 0.120 | 0.262 | 0.381 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | -0.008 | -0.014 | -0.712 | -0.003 | -0.124 | -0.037 |
| Std Dev | 0.242 | 0.161 | 0.916 | 0.120 | 0.262 | 0.381 |
| | | | *Depth to Groundwater (feet)* | | | *Filtered Sales (acre-feet)* |
| Counterfactual Data | | | | | | |
| Mean | 182.99 | 132.57 | 276.81 | 207.21 | 243.60 | 4758.85 |
| Std Dev | 48.40 | 37.01 | 86.58 | 207.21 | 87.13 | 2442.31 |
| Percentage Difference from Actual Data | | | | | | |
| Mean | -0.024 | 0.004 | -0.032 | -0.002 | 0.003 | 0.001 |
| Std Dev | 0.065 | 0.043 | 0.020 | 0.062 | 0.036 | 0.156 |
| Percentage Difference from Base Scenario | | | | | | |
| Mean | -0.027 | -0.002 | -0.024 | -0.005 | 0.006 | 0.006 |
| Std Dev | 0.065 | 0.043 | 0.020 | 0.062 | 0.036 | 0.156 |

Notes: This table compares the counterfactual actions and states with the actual and Base scenario actions and states.

# C Additional Discussion of Empirical Approach

## C.1 Residential Water Demand

As part of the estimation procedure, we estimate the residential household water demand function in the following equation, which is then used to estimate consumer surplus and water sales revenue for water districts. The following discussion is taken from Sears et al. (2023c).

Our observational unit here is a water district in a given year. Our regression model is given by:

$$lnq_i = \alpha_0 + \alpha_1 ln[P_i] + \alpha_2 ln[f_i] + X_i'\alpha_3 + \epsilon_i, \tag{C.1}$$

where $q_i$ is the quantity of household monthly water consumption in water district $i$; $P_i$ is the residential water price in water district $i$; $f_i$ is the average household size in district $i$; and $X_i$ is a vector of controls, which include median per capita income, state-wide unemployment, precipitation, and rate structure design.

Since residential water price is endogenously determined by both supply and demand for water, we employ an instrumental variables approach, as is common in the literature on residential water demand (Worthington and Hoffman, 2008). Here we instrument for the price of water with supply shifters. Specifically, our instruments for price are the annual equivalent unit price charged by the State Water Project (SWP) for water delivery to the water district's nearest State Water Project contractor, and the product of the average depth to groundwater in the district and the price of electricity. These supply shifters are correlated with price because water district costs are generally included in the pricing formula for the district. Since water districts draw on groundwater, surface water, and water imports to meet their supply needs, these instruments clearly affect the cost of the water district's supply.

We believe that these instruments also satisfy the exclusion restriction. The State Water Project (SWP) price for water delivery to the district's nearest State Water Project contractor is determined by the State Water Project, and reflects the costs of transporting water, obtaining supplies, and maintenance (California Department of Water Resources, 2016b). Since the State Water Project does not sell directly to water districts, but rather to large contractors who then sell water to the water districts, no single district can fully determine the demands of a contractor, and the pricing rule used by the SWP is not driven by the demands of any single contractor. Furthermore, differences across contractors in price are driven mainly by differences in location, and the maintenance and capital costs of the pipelines that transport water to each district. Thus, the State Water Project (SWP) price for water delivery to the district's nearest State Water Project contractor is a supply shifter that does not affect residential water demand except through its effect on the residential water price. The average depth to groundwater in the district interacted with the price of electricity is similarly a supply shifter that does not affect residential water demand except through its effect on the residential water price. We conduct several tests of both correlation and the exclusion restriction, and find evidence that is consistent with our instruments being both relevant and valid. The Sanderson-Windmeijer first-stage F-statistic (Sanderson and Windmeijer, 2016), which is a modification and improvement of the Angrist-Pischke first-stage F-statistic (Angrist and Pischke, 2009), is equal to 199, which is greater than the threshold of 10 used in current practice (Staiger and Stock, 1997; Stock and Yogo, 2005; Andrews et al., 2019), and also greater than the threshold of 104.7 for a true 5 percent test (Lee et al., 2021).

For our water demand estimation, we use pooled data from the bi-annual California/Nevada Water Rate Survey conducted by the American Water Works Association. We do not treat our data as a panel due to the infrequency of repeated observations in our data. We use data on household size by city and county from the California Department of Finance; data on median adjusted gross income by county from the California Franchise Tax Board; and data on the industrial average electricity price for California from the US EIA. Our dataset covers the years 2007-2015. Summary statistics are presented in Table A.4 in the Appendix.

Our empirical results for the residential water demand function can be found in Table C.1. We find elasticities of price and household size that fit with our prior belief that demand should be inelastic with regard to each, and fit within the bounds of prior results in the literature (Worthington and Hoffman, 2008). Since the coefficients on the variables in the vector $X_i$ of controls are not significant at a 5% level, we do not include these variables as determinants of water demand in our structural model, but instead account for them by solving for the constant $\hat{A}$ that equates mean predicted household consumption (using only price and household size as predictors) with actual consumption.

Table C.1: Residential Water Demand

| | *Dependent variable is: Log Quantity of Household Monthly Water Consumption (hundred cubic feet)* |
|---|---|
| Log Average price paid by the user (dollars per hundred cubic feet) | -0.321** |
| | (0.100) |
| Log Average household size in city | 0.407** |
| | (0.137) |
| Log Median personal income in county (dollars) | -0.142 |
| | (0.144) |
| Log Unemployment rate in state | 0.00281 |
| | (0.0573) |
| Log Precipitation in county, full year (inches) | 0.0158 |
| | (0.0304) |
| Structure = 2, Declining | -0.0284 |
| | (0.204) |
| Structure = 3, Inclining | -0.0328 |
| | (0.0609) |
| Structure = 5, Other | 0.00915 |
| | (0.0974) |
| Structure = 6, Uniform | -0.0652 |
| | (0.0829) |
| Constant | 3.792** |
| | (1.422) |
| Observations | 210 |
| R-squared | 0.645 |
| RMSE | 0.253 |
| **Instruments for residential water price** | |
| Charge for water supply for closest SWP contractor (dollars per acre-foot) | Y |
| Log Depth to groundwater (feet) X Electricity price in water district (dollars per kwh) | Y |
| Sanderson-Windmeijer first-stage F-statistic | 199 |
| Anderson underidentification test p-value | 0.000106 |
| Stock-Wright p-value | 0.0167 |
| Hansen J test p-value | 0.449 |

Notes: Standard errors in parentheses. We use two supply shifters to instrument for residential water price: the annual equivalent unit price charged by the State Water Project (SWP) for water delivery to the water district's nearest State Water Project contractor; and the product of the average depth to groundwater in the district and the price of electricity. Significance codes: *** p<0.001, ** p<0.01, * p<0.05