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Property Rights and Water Transfers: Bargaining Among Multiple Stakeholders*

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ABSTRACT

Both developing and developed countries constantly face problems related to ill-defined property rights in common-pool resource systems. These problems are especially acute in water resource ecosystems. A natural consequence of incomplete property rights is the substitution of market-determined exchange by negotiation-determined exchange. Water rights in the western region of the United States provide an excellent example. This paper is a case study of the negotiations over a water transfer from California's Imperial Valley to San Diego County in light of the transfer's impact on the inland Salton Sea. We analyze these negotiations as a multi-issue, multi-party, non-cooperative negotiating game. We construct stylized representations of the payoff functions for each party as well as of the physical, economic, and political constraints. To model the default outcome, we assign probabilities to various contingencies that might have arisen had the parties been unable to negotiate an agreement. We calibrate the model to the final agreement

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and then focus on the impact on the negotiated outcome of certain features of the institutional landscape: the influence of the allocation and specification of property rights; what would have happened if a producer group had negotiated directly with the urban stakeholder; the role of certain critical features of the Law of the River; and the impact of environmental regulations.

Keywords: Property rights; bargaining; Colorado River; Salton Sea; Law of the River; stakeholder bargaining; water rights.

INTRODUCTION

Property rights play a pivotal role in modern societies and economic analysis. Well-defined and clearly articulated property rights are a principal source of economic growth and well-being. Without sound governance structures, including the rule of law, any system of ill-defined property rights is destined to under-perform. In common-pool resource systems, when resource units are highly valued, appropriations made by one stakeholder often create negative externalities for others (Rausser and Zusman 1992). The "tragedy of the commons" first identified by Hardin (1968), and extensively studied by Ostrom (2002), is a natural phenomenon that emerges in highly valued, open-access commons where those involved have not established an effective governance structure. This is especially true in many water resource ecosystems throughout much of the world. A natural consequence of the ill-defined property rights in water resource systems is the substitution of market-determined exchange by negotiation-determined exchange. Such negotiations generally take place at two levels: first, setting the governance structure including the assignment of property rights, and second, facilitating the allocation or exchange of water flows from one group or individual to another.

As emphasized by Ostrom (1991, 1997), water resource systems are not governed entirely by stakeholders; instead some rules are made by local, regional, national, or even international authorities. Typically, such authorities do not specify a well-articulated set of property rights. In many parts of the world, increased water scarcity has created pressure to re-allocate water. Given the incomplete governance structures and ill-defined property rights surrounding water allocations, negotiation or bargaining among the various stakeholders is necessary to achieve improved efficiencies.

Indeed, Rausser (2000) argues that for a variety of reasons, most decisions in water systems are made collectively. Such decisions can include both the construction and operation of water infrastructure and decisions about the legal rules or property rights under which users have access to water. As a result, the analysis of water policy change requires an analytical framework capable of addressing collective action. Rausser suggests the use of game theoretic models of collective choice.

This perspective has gained considerable popularity in recent years, both in the study of water institutions and other environmental and resource allocation issues (e.g., Dinar *et al.* 2008). Carraro *et al.* (2007) and Simon *et al.* (2007) provide detailed reviews of the literature on applying bargaining theory to water policy negotiation. Adams *et al.* (1996) use a bargaining model to analyze negotiations over water allocation in California between agricultural, urban, and environmental interests. Simon *et al.* (2007) use a similar model to analyze water allocation between different subbasins of the Adour water basin in France. Netanyahu *et al.* (1998) apply both cooperative and non-cooperative bargaining models to groundwater allocation between Israel and Palestine. Just and Netanyahu (1998) investigate the divergence between "ideal" basin-wide management of multi-national river basins and the real world experience of bi-lateral agreements within these basins. Goodhue *et al.* (2009, 2010) use bargaining theory to discuss negotiations over the future of the Sacramento-San Joaquin Delta. Dinar *et al.* (1992) and Parrachino *et al.* (2006) review the literature on applying cooperative game theory to water negotiations. Ambec and Ehlers (2008) analyze water sharing among a group of satiable agents using cooperative game theory. Dinar *et al.* (2006) compare cooperative and negotiation approaches to analyzing water allocations in South Africa's Kat Basin.

In this paper, we use a bargaining theoretic framework to analyze and evaluate the transfer of water from agricultural to urban uses in the context of ill-defined property rights, using as a case study the so-called San Diego-Imperial Valley Water Transfer Agreement (WTA) finalized in October 2003.[1] This agreement represents the largest long-term water transfer in California history. The actual negotiations were fraught with ill-defined property rights and much of the bargaining took place at both levels of negotiation: articulating property rights and transferring water resources from one stakeholder group to another. Due to the large scale of the transfer and the lessons learned, the resulting outcome is likely to have a significant influence on any future water transfer in the United States and perhaps elsewhere.

In this case study, the governance rules specifying the number of stakeholders, the issue spaces, stakeholder access, admissible coalitions, and default options proved critical. For example, the parties originally failed to reach an agreement, suggesting that none of the feasible options Pareto dominated the default outcome. However, when government actions following the failure of negotiations shifted the default outcome, a Pareto improvement became available and agreement was reached. Our bargaining model is calibrated to be consistent with these two historical events. Using the calibrated model, we conduct a series of counterfactual simulation experiments to explore how alternative property rights regimes and other factors can impact the outcome of negotiations. We focus particular attention on both the allocation and extent of the rights that were being traded during the negotiations and the nature and security of these rights. Following a brief description of the institutional history of water rights in the western United States in the next section, we discuss the role that property rights played in the negotiations.

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[1] On February 11, 2010, California Superior Court Judge Roland L. Candee invalidated many of the agreements underlying the QSA. The water agencies filed an appeal and have been granted a stay allowing the transfers to continue for the time being. At the time of this writing, the final legal resolution is unknown.

In the following section, we conceptualize the WTA negotiations as a multilateral bargaining game. The final section offers some concluding remarks.

HISTORICAL AND INSTITUTIONAL BACKGROUND

When settlers originally arrived in the western United States, there were no defined property rights to water. Settlers simply diverted the water they needed. No economist should be surprised that treating water as a common property resource in this fashion quickly resulted in problems. While initially there was enough water for the few settlers, conflicts quickly arose. As increasing numbers of settlers put demands on the rivers of the region, some system was required to allocate water among competing interests. Matters were further complicated by seasonal and annual fluctuations in the amount of water available. The governance structure that emerged for the Colorado River is based on a complex body of agreements, legislation, and court decisions, collectively known as the "Law of the River."

The Colorado River Compact of 1922, the Boulder Canyon Project Act of 1928, and the Mexican Water Treaty of 1944 allocate the river's annual flows between Mexico and the seven U.S. states bordering the river. The 4.4 million acre feet (maf) allocated to California is divided among internal California agencies under the Boulder Canyon Project Agreement of 1931 (the Seven-Party Agreement). While the vast majority of California's imported water has historically been used for agriculture, the growth of urban water demand has far outstripped that of agricultural demand. For instance, in 1960, urban water users in California used 2 maf/year. By 1995, they used approximately 9 maf/year. Current projections indicate that by 2020, they will use 12 maf/year. In contrast, agricultural water use is expected to decline slightly from its 1995 level of 34 maf/year to approximately 32 maf/year by 2020 (Department of Water Resources, 1998). Because the Seven-Party Agreement was signed when urban demand was relatively low, agricultural users have legal rights to most of the state's imported water. Under the Seven-Party Agreement, the first 3.85 maf of California's share of Colorado River water belongs to the primarily agricultural uses of Palo Verde Irrigation District (PVID), the Yuma Project, Imperial Irrigation District (IID), and Coachella Valley Irrigation District (CVWD), in that order. The remaining 550 thousand acre feet (kaf) of California's allotment belongs to the Metropolitan Water District (MWD), which serves most of urban Southern California, including San Diego County. Figure 1 provides a rough schematic of the geographic relationship between these agencies.

Historically, because of a combination of surplus river flows and low demand by Arizona and Nevada, California has been able to divert 5.2 maf of the Colorado's annual flow or approximately 20% more than its 4.4 maf allotment. The first 662 kaf of diversions above the 4.4-maf limit are granted to MWD. The next 300 kaf are granted to the agricultural districts, and any remaining water is allocated to other agricultural purposes. Recently, however, a multi-year drought across the West, coupled with an increasing population has put extreme pressure on water delivery systems. In particular, due to rapid growth in Arizona and Nevada, those states now demand their full allotment of

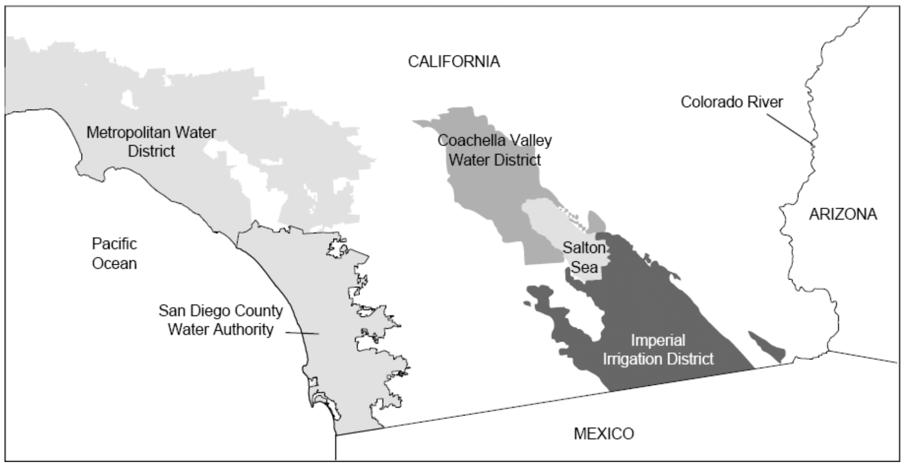

Figure 1. Geographic schematic.

Colorado River water. Under an agreement known as the Interim Surplus Guidelines, California will be given 15 years to gradually reduce its use to its legal allotment, as long as certain conditions are met. In recognition of changing circumstances within California, one of those conditions is a significant reduction in agricultural water use within the state. Another important condition is that the state must create a workable plan to meet the Guidelines' targets.

The cornerstone of the state's plan is known as the Quantification Settlement Agreement (QSA). The QSA is a set of agreements designed to clarify and quantify property rights, thereby facilitating the transfer of water from agricultural to urban uses. It includes agricultural districts' agreements to voluntarily limit their uses and thereby create a guaranteed quantity of water for lower-priority users. In return, the lower-priority users agree not to challenge IID's water rights on the basis of its irrigation practices. The agreement also encompasses a significant step in reducing agricultural use, the Water Transfer Agreement (WTA) between IID and San Diego Country.

Imperial County, one of the poorest counties in the state, is heavily dependent on agriculture. With virtually no natural rainfall, the county's farmers are entirely dependent on irrigated water. There is significant scope for efficiency improvements in the District's water delivery and farm irrigation systems, as approximately 31% of the water applied to fields ends up in the District's drains as agricultural runoff. However, the installation of such systems is not cost-effective for farmers, due to low water prices and narrow profit margins.

Meanwhile, neighboring San Diego County is one of the fastest-growing regions in California. This county is also dependent on imported water, having little or no groundwater or rainfall. The San Diego County Water Authority (SDCWA) imports between 75% and 95% of the region's water, all purchased from MWD. Following a period of water cutbacks from MWD, SDCWA has taken steps to secure a more reliable water supply.

In the mid-1990s, SDCWA began negotiating with IID about the possibility of buying water from Imperial Valley. Initially, the parties envisioned a fairly straightforward agreement. San Diego would purchase a large quantity of water from IID for a considerable price. The revenues from the transfer would allow IID to improve its delivery systems and help farmers pay to install water conservation technology. The efficiency gains would allow IID to transfer water to San Diego without impacting the region's agricultural production. However, stumbling blocks arose quickly.

CVWD argued that IID's right to water did not include the right to sell it. They claimed that the priority system laid out in the Law of the River granted CVWD the right to any water that IID did not use and therefore that water could only be transferred to San Diego with CVWD's approval. During the negotiations over the WTA, CVWD refused to allow the transfer to go through unless IID agreed to sell 100 kaf/year to CVWD in addition to any amount sold to San Diego.

While CVWD made negotiations more difficult, it was concern over the Salton Sea (the Sea) that nearly killed the WTA. The Sea is an inland salt lake close to the Mexican border in Imperial and Riverside counties. It receives virtually no rainfall or natural inflow and would thus quickly dry up without the agricultural runoff from IID and CVWD. Because the sea has no outlet, salts are concentrated in the sea by evaporation, continually raising salinity levels. Currently, the sea has a salinity level of approximately 44 grams/liter (g/L). (In comparison, the salinity of the Pacific Ocean is 35 g/L.)

The sea provides important habitat for many bird species. Four species in particular — white pelicans, brown pelicans (a state and federally listed species), black skimmers (a California species of special concern), and double-crested cormorants — feed on fish, primarily tilapia, from the sea. It is generally accepted that as the salinity of the sea increases, the fish populations will collapse, robbing the birds of an important food source. Projections indicate that if present trends continue, salinity in the sea will reach 60 g/L by 2023, at which level the tilapia fishery is likely to collapse (Final Environmental Impact Report/Environmental Impact Statement (EIR/EIS), 2003).

Environmentalists quickly realized that the original plans to generate transfer water through conservation would significantly diminish water drainage into the sea, thus accelerating both the rise in its salinity and the reduction in its elevation. If 300 kaf per annum were transferred, using water generated only through conservation technologies, the tilapia fishery is projected to collapse as soon as 2012 (EIR/EIS, 2003). To address this concern, environmentalists insisted that fallowing should replace conservation as the principle method to generate water for the transfer.

By October 2002, a basic agreement had been reached among the major parties. The agreement involved water transfers to San Diego that ramped up to 130 kaf/year for the first 15 years of the agreement and increased to 200 kaf/year by 2021. The ramp-up period was necessary to allow IID time to implement the changes needed to generate water for transfer. For the first 15 years, all transfer water would be generated by fallowing and IID delivery system improvements. In return, San Diego would pay a per-acre-foot fee and provide $20 million to mitigate socioeconomic impacts. IID also agreed to sell

100 kaf/year to CVWD. For a period of 15 years, IID would be required to maintain the mean salinity trajectory that would have obtained in the absence of a transfer.

While IID landowners supported this agreement, the wider Imperial Valley community strongly opposed the fallowing provisions. Ultimately, the IID Board rejected this plan and agreed to a last-minute alternative, touching off a firestorm over California's water. MWD rejected the new plan, and the United States Department of Interior (Interior) announced that it would cut California's deliveries back to the 4.4-maf limit and reduce IID's deliveries by 11%, effective immediately. While the federal government argued that the cuts to IID were legitimate due to the District's inefficiency, IID filed a lawsuit protesting the decision. Simultaneously, a group of landowners within Imperial Valley filed another suit against the IID Board, arguing that the District's water rights really belonged to the landowners who now wished to exercise their right to sell the water, regardless of objections raised by the rest of the County community.

In October 2003, the parties finally approved a revised proposal. This change of heart can be explained in part by several events that occurred during the interval between December 2002 and October 2003. First, a potentially promising scenario for preserving the Salton Sea emerged. Environmental activists realized that an agreement could provide funds for the construction of a dike across the middle of the Sea, so that the northern half of the Sea could be maintained as a marine lake. The southern half would become hypersaline but still provide wetland habitat. Once the negotiating parties became convinced this small Sea scenario had merit, it was agreed that IID's obligations regarding runoff to the sea would change if the smaller lake became a reality. With this modification, IID agreed to accept the need for fallowing in the short term.

Meanwhile, the parties learned about the significant consequences of failing to agree. There is considerable speculation that IID did not believe that Interior would follow through on earlier threats to cut the District's water if an agreement was not reached by December 31, 2002. Presented with undeniable evidence that maintaining its historical rights would require an uphill legal battle, the District concluded that its objections to the proposed agreement were dwarfed by the problems it would face if the agreement fell through. On the other hand, MWD held up the agreement throughout most of 2003, refusing to contribute to the Salton Sea mitigation fund. Finally, bowing to political pressure and threats from the state, MWD decided that agreement was in its best interest. In the specification of our bargaining model below, we shall refer to the outcome that was finally negotiated in October 2003 as The Agreement.

As this brief history indicates, many factors shaped the final agreement. Property rights play a role in most of these. In the next section, we identify several property rights issues and raise a series of questions about how alternative property rights regimes might have changed the outcome.

PROPERTY RIGHTS AND BARGAINING

We address the relationship between property rights and the WTA negotiation at two levels. The first, relatively straightforward level relates to the allocation of rights to the water being transferred among the parties to the agreement. The second, more subtle and fundamental level relates to the actual nature of the parties' rights.

Because Western water law is based on a "first-come, first-served" principle, water rights have been allocated largely on the basis of who began diverting water first. Imperial Valley's huge claim to Colorado River water originated with diversions by its landowners during the 1800s. In the early 1900s, landowners assigned their water rights to mutual water companies, which built and operated canals to deliver water. IID acquired several of these companies and eventually controlled all of Imperial County's water.

In contrast to many water districts, which are exclusively controlled by farmers and landowners, the IID Board is elected by the voters of the entire Imperial Valley. Consequently, Board members have been concerned about the impact of the WTA on the wider community, not just on landowners. When the Board decided to reject the October 2002 deal due to concerns over fallowing, a group of landowners objected. They filed a lawsuit, alleging the Board held the rights in trust for the landowners who were the original water diverters. The landowners claimed that by failing to sign the agreement, the Board was mismanaging those rights and that they should therefore be returned to landowner control. To investigate how the agreement would have evolved had the landowners' action been successful, we simulate a bargaining scenario in which the IID is replaced at the bargaining table by a representative answerable solely to the landowners.

Another important factor that impacts property rights is the Endangered Species Act (ESA). Here the issue is not who owns the rights, but what entitlements come with ownership. The ESA is often vilified by property owners, because of the restrictions it imposes on their rights and because it fails to balance the social costs associated with implementing these restrictions with the environmental benefits they are designed to achieve. Our present context provides an illustration of both issues. Perhaps the major impediment to reaching agreement over the WTA has been that the ESA severely restricts the options by which IID can compensate for the resulting loss of water. In particular, IID's preferred alternative — to install tail-water recovery systems — is prescribed because it would increase the salinity of the Salton Sea and thus negatively impact the habitat of endangered pelicans that feed on the tilapia within it (State Water Resources Control Board, 2002). Landowners and farmers view this proscription as a serious infringement on their property rights. The environmentalists' position is that water is a public resource and that rights to it must be shared between agricultural users and "environmental stakeholders." In our simulations, we investigate the consequences of more or less restrictive specifications of the ESA, including specifications in which the pelicans' claims to water are either absolute or subject to a cost-benefit evaluation.

While the ESA amounts to a partial transfer of landowners' water rights to the environment, the evolution of the Law of the River severely restricts the manner in which this transfer can be effected. In contrast to the way water law is implemented elsewhere in California (United States Court of Appeals, 2004), this law proscribes the delivery of Colorado River water for any purpose other than agricultural and "domestic" uses. Since the latter are explicitly enumerated and do not include environmental objectives

(Colorado River Compact, 1922, Article II(h) and III(e)), a natural and potentially efficient solution to the Salton Sea problem — diverting water directly from the river to the Sea — is precluded by law. It seems probable that had this solution been available, the WTA negotiations might have proceeded much more smoothly and reached a more satisfactory outcome. We explore this conjecture by constructing a simulation experiment in which the bargaining space is expanded to include the possibility of direct diversions. (In fact, the negotiated agreement does involve the transfer of some water to the Salton Sea Authority for the purposes of mitigating salinity impacts. However, this arrangement had to be very carefully orchestrated; the water is to follow a convoluted path, painstakingly designed so that in a technical sense it satisfies the legal requirements of the Law of the River.)

The simulation experiments described above all involve reallocating water rights among the various parties to the negotiations. In another set of experiments, we address the impact of incompleteness in the specification of these rights. All water rights are held subject to the requirement that the water be "reasonably and beneficially" used. This precept protects lower-priority water users from wasteful practices by those higher in the queue. But the benchmark for determining what usage is reasonable and beneficial is by no means clear-cut. Competing claimants have argued that Imperial Valley farmers use water in a profligate and inefficient manner, but nobody knows for certain what criterion a court would apply to determine whether their usage was "unreasonable." For this reason, landowners in the Valley have long been concerned about the security of their water rights. The evolution of the WTA negotiations clearly reflects this insecurity (Allen, 2003), while the final Agreement insulates IID from legal challenges by other signatories to their rights. A natural conjecture is that the transfer would have been structured quite differently, and probably more efficiently, had the IID felt that their property rights were invulnerable. To simulate this counter-factual, we include a variable in our model representing security of property rights, and compare the outcome of negotiations, depending on whether this variable is subject to negotiation or is exogenously fixed at "fully secure."

There is a second sense in which IID landowners' property rights are incompletely specified. Once again, the incompleteness arises from the concept of "reasonable and beneficial use," but in this case, the problem is that the Law of the River evolved long before anyone ever conceived of the possibility of a massive ag-to-urban water transfer. In the Seven-Party Agreement, IID stands before CVWD in the priority line for Colorado River water. This means that IID is entitled to as much water as it can reasonably and beneficially use, up to a set limit, while CVWD has a claim to whatever portion of this entitlement remains unused by IID. When IID proposed transferring some of its water to San Diego, CVWD immediately objected, on the grounds that under the Law of the River, this would not be considered to be reasonable and beneficial use by IID. CVWD used this leverage to induce IID to provide it with 100 kaf of water at a price well below market rates. Had the Law of the River explicitly specified whether transfers would be considered a reasonable and beneficial use, Coachella's role in the negotiations would have been quite different. To evaluate the role of this gap in the law, we simulate the outcome of the negotiations under both possible resolutions of the uncertainty.

THE BARGAINING MODEL

A bargaining game is built around three basic elements: (1) a set of issues over which players bargain, (2) a group of players, together with their payoffs over the space of issues, and (3) a default outcome. In this study, we focus on six parties directly involved in the bargaining: four Southern California water agencies (IID, SDCWA, CVWD, and MWD), the State of California, and an environmental advocate. A seventh party — the federal government — is excluded from the bargaining table: while this party played an important role in the negotiations, it was primarily to determine a critical piece of the default outcome — who had the rights to how much water in the absence of an agreement. Each of the parties at our bargaining table is a composite, aggregating an array of different interests. For example, our environmentalist represents all of the various environmental groups concerned about the Salton Sea. In the case of the IID, the component subgroups are sufficiently important that we explicitly model their preferences, and specify the IID's utility as a weighted average of the utilities of its constituents.

The specification of exactly what these six players were bargaining over is fairly complex. The entire set of QSA negotiations covers a broad variety of issues and modeling every nuance is impractical. Accordingly, we model our players as bargaining over a set of variables that we believe reflect the most important aspects of The Agreement. These variables are listed in Table 1, the last column of which shows the values in The Agreement corresponding to all but one of the variables. Together, these variables make up an agreement vector $\mathbf{b}$. The values of these variables in the event of negotiation failure are denoted by the default vector, $\mathbf{b}_d$.

There are six types of bargaining variables. The first governs the distribution of water. The State of California has a basic right to 4.4 maf of Colorado River water a year. We allow the parties to bargain over the division of this water, after subtracting the noncontentious 9.9% consumed by Palo Verde, the Yuma Project, and various Native American tribes. If the agreement meets the requirements of the Interim Surplus Guidelines, the state may be able to take additional water until 2017. MWD holds the rights to this surplus water, so under any proposal meeting the Guidelines, we take into account the possibility of additional water for MWD. Finally, we allow for the possibility that the Salton Sea might have a claim on a share of the water, so that we can investigate the implications of relaxing the Law of the River's proscription on piping water directly into the Sea.

The second section of Table 1 concerns annual payments resulting from the distribution of the water. In The Agreement, San Diego agreed to pay IID for the water it receives and pay MWD for the transportation of that water. CVWD will pay IID for its water as well. In our bargaining model, we require that annual payments sum to zero across the four water agencies. Section 3 of the table concerns a set of lump-sum payments. These include payments for mitigation of environmental impacts on the Salton Sea, socioeconomic impacts within IID, and payments for lining the All-American and Coachella canals. The cost of lining the canals is actually paid by IID and CVWD and is not subject to negotiation, but through the bargaining, other parties may reimburse them for these expenses. Again, we require the lump-sum payments to sum to zero

Table 1. Bargaining space variables.

Variable description	The Agreement
Shares of California's 4.4 maf Basic Allotment	
b_{W_SD} San Diego Water Share	—
b_{W_IID} IID Water Share	—
b_{W_CVWD} Coachella's Water Share	—
b_{W_O} Combined Share of PVID, Yuma, and Native American Tribes	—
B_{W_E} Salton Sea Share	0.000
b_{W_MWD} MWD's Share is $1 - b_{W\_\mathrm{SD}} - b_{W\_\mathrm{IID}} - b_{W\_\mathrm{CVWD}} - b_{W\_O}$	—
Annual Payments (Millions of Dollars) (totals do not sum to 0 due to rounding)	
b_{A_IID} Annual Payments To (From) IID	66
b_{A_SD} Annual Payments To (From) SD	(83)
b_{A_MWD} Annual Payments To (From) MWD	31
b_{A_CVWD} Coachella Payments are — $(b_{A\_\mathrm{IID}} + b_{A\_\mathrm{SD}} + b_{A\_\mathrm{MWD}})$	(15)
Initial Lump-Sum Payments (Millions of Dollars)	
b_{M_SS} Net Payments to Salton Sea Mitigation	133
b_{M_IID} Net Payments to (from) IID	(24) + AAC^a
b_{M_SD} Net Payments to (from) San Diego	(72) – (AAC^a + CC^b – 220)
b_{M_MWD} Net Payments to (from) MWD	0
b_{M_CVWD} Net Payments to (from) Coachella	(37) + CC^b
b_{M_S} Dollars to (from) State are — $(b_{M\_\mathrm{SS}} + b_{M\_\mathrm{IID}} + b_{M\_\mathrm{SD}} + b_{M\_\mathrm{MWD}} + b_{M\_\mathrm{CVWD}})$	(220)
b_{MS_MWD} Supplemental Payment from MWD tied to surplus water	(20)[c]
Salton Sea Liability	
b_{L_IID} IID's Share of Salton Sea Liability	0
b_{L_SD} San Diego's Share of Salton Sea Liability	0
b_{L_MWD} MWD's Share of Salton Sea Liability	0
b_{L_CVWD} Coachella's Share of Salton Sea Liability	0
b_{L_S} State's share is $1 - b_{L\_IID} - b_{L\_SD}$	1
Mitigation Water	
b_{MW} Water Contributed by IID to Salton Sea Mitigation	1600 kaf
b_{MWSP} Price Paid to IID by DWR for Mitigation Water	\$175
b_{MWPP} Purchase Price of Mitigation Water	\$250
Other Parameters	
b_{R} Ramp-Up Period	21 Years
b_{D} Parameter Governing the Security of IID's Right	0.85–0.95

[a]The (unknown) expected cost of lining the All-American Canal.
[b]The (unknown) expected cost of lining the Coachella Canal.
[c]Possible additional contribution to mitigation; dependent on availability of surplus water

over all parties and only consider the net payment of each party. For instance, in The Agreement, IID pays $46 million for environmental mitigation, but receives $20 million for socioeconomic impacts and reimbursement for canal lining expenses, resulting in a net outlay of $26 million less the cost of lining the All-American canal. The last line of this section represents supplemental payments by MWD for Salton Sea mitigation tied to the receipt of surplus water. In The Agreement, MWD agreed to contribute $20 to the Salton Sea mitigation fund for every acre-foot of water received under the Interim Surplus Guidelines. Our bargaining space is designed to include both this arrangement and the possibility that MWD could have contributed funds independent of receiving the surplus water.

Section 4 of the table covers liability allocation. Although The Agreement includes provisions for restoring the Salton Sea, it is possible that adequate restoration will be infeasible or that it will require more money. In this case, the State agreed to assume all liability. During the negotiations, however, there was discussion about whether some or all of the liability would be shared between IID and SDCWA. Accordingly, we model the parties as bargaining over the division of this liability, requiring that the liability shares sum to unity.

As part of The Agreement, IID agreed to sell a portion of its negotiated share of water to the Department of Water Resources (DWR), for the purposes of reducing salinity in the Salton Sea. Under some circumstances, the DWR will resell this water to MWD, to generate additional revenue for Salton Sea restoration. Accordingly, in section five of the table we represent this aspect of the agreement by three variables: the total amount of water IID provides for Sea mitigation, the price at which IID sells it to DWR, and the price at which MWD purchases the water.

The final section consists of two miscellaneous parameters. Because the water transfers in the agreement increase gradually over time, we include a ramp-up period in the bargaining space. While the ramp-up schedules in The Agreement are somewhat complex, we simplify matters by admitting only straight-line schedules; we also require our players to negotiate over a single date that determines the ramp-up interval. Our last variable, representing the security of IID's water rights, differs from the others in that it has no natural numeric counterpart in The Agreement. As discussed below, IID's water rights are not entirely secure. CVWD and MWD have often indicated their belief that IID's water use is not "reasonable and beneficial" to the extent that its irrigation practices are inefficient. Reflecting the possibility that either CVWD, MWD, or the federal government might prevail in a legal challenge to IID's water rights on this basis, we model the amount of water IID can expect to have in the future as a random variable whose distribution, represented by a single parameter, is subject to negotiation. This parameter is, obviously, a stylization of qualitative factors that are extremely hard to quantify. For example, we can interpret the declarations by CVWD and MWD that they will not challenge IID's water rights during the term of the QSA as reducing IID's uncertainty over its rights, but since the federal government is not bound by these agreements, it would be difficult to justify any point estimate of the magnitude of the reduction. We therefore consider a range of possible values for this reduction. While these quantification problems cause concern, the inclusion of this uncertainty variable in the bargaining space nonetheless enables us to explore qualitatively how the negotiation might have evolved differently if IID's property rights had been more secure under the status quo. If IID were to lose some of its water following a challenge, we assume that the water would be granted to the next lower-priority party. That is, CVWD would have first rights to the water until the total amount taken by Palo Verde, Yuma, IID, and CVWD totals 3.85 maf. The remaining water would be allocated to MWD.

In textbook bargaining problems, the parties care directly about the issues they negotiate over. In the present, more complex situation, their utilities are defined over variables such as revenues and profits, whose levels are linked to the outcome of the bargaining via structural economic relationships. A schematic of these relationships is shown in Figure 2. The bargaining space is represented in the upper left corner. Moving counter-clockwise around the outside of the figure, we see that for each outcome of the bargaining negotiations, the IID must adjust the settings on various policy instruments under its control to implement the provisions of the bargaining outcome. These instruments include delivery system improvements, the price of water, payments for land fallowing, direct constraints on water use, and subsidization of on-farm conservation technology. We refer to the settings on these instruments as an *implementation vector*. Next, for each such vector selected by IID, the farmers optimize their production in response. Farmers decide how much land to plant with each crop, how much land to fallow, and the levels of water and irrigation capital to use for each crop. The implementation vector, as well as farmers responses, are selected, once and for all, at the outset of the time horizon, and, together with the realization of certain random variables, fully determine the evolution of the economy over this horizon. Specifically, these decisions determine, for each year in our time horizon, an annual *result vector* and a salinity trajectory.

The result vector in turn affects the utility of both the IID Board members and of various constituency groups within the Valley. Together, the members' and the constituency groups' utilities determine the IID Board's utility for that year. Thus, for each bargaining outcome, IID selects the implementation vector that maximizes the present discounted value of the Board's utility, taking into account farmers' responses.

The result vector also has an impact on the Salton Sea. We use a salinity model — depicted in the center of Figure 1 — to simulate the impact of the result vector implied by the bargaining outcome on the salinity and elevation of the sea. This model incorporates changes in inflows to the sea resulting from both changes in farmers' production decisions and system improvements undertaken by IID. The sea's elevation affects Imperial Valley utility through its impact on dust, while the salinity affects the Board, because IID is responsible for maintaining a specified salinity trajectory for the Sea.

The mean and variance of the salinity trajectory also affect the long-term viability of the sea, which affects the utility of all players, especially the environmentalists. There are many variables affecting the feasibility of any restoration scenario. The inflow of water and money to the restoration effort is perhaps the most important. To model this impact, we construct a mapping, $\pi_s(\mathbf{b})$, from the bargaining variables to the probability that a viable sea can be maintained indefinitely. This probability increases as the amount of money and water contributed to Salton Sea mitigation increases and as the projected salinity and variance decrease.

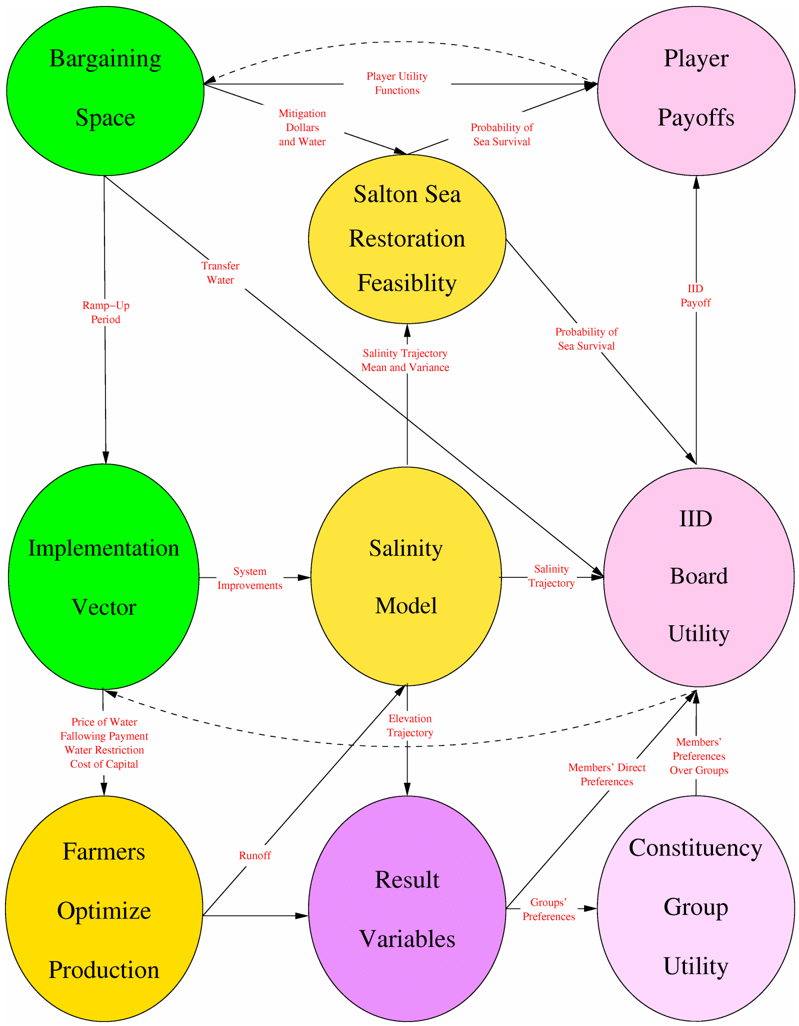

Figure 2. Bargaining game.

In the following subsection, we specify utility functions for each party involved in the negotiations, together with linkages between the variables being negotiated and the arguments of parties' utilities.

The Stakeholders

There are six stakeholder groups in our model, indexed by i. The stakeholder groups, with abbreviations for use in our equations, are: Imperial Valley Irrigation District (IID), San Diego (SD), Metropolitan Water Authority (MWD), Coachella Valley Water District (C), the State of California (S), and the environmentalists (E). The three water agencies other than IID are primarily concerned with the amount of water they receive and the amount of money they have to pay for it, while the state is concerned with the efficient allocation of water across agencies. The environmentalists are focused on preserving the Salton Sea. The IID represents a much more diverse collection of interests.

The Imperial Irrigation District

The five-person IID Board represents the Imperial Valley at the negotiating table. The Board is elected by the voters of Imperial Valley and has jurisdiction over the activities of the IID. While the Board is represented in our bargaining model by a single player, this player's utility is a composite, reflecting the competing interests of the various constituencies within the Valley. Specifically, the IID's utility is an unweighted average of the utilities of each of its board members; each board member's utility is, in turn, a weighted average of her own personal preferences and those of the constituency groups that comprise her political base. We identify six constituency groups, indexed by j, within the Imperial Valley, each with distinct interests: landowners, landowner/operators, operators, labor and ethnic interests, non-labor input suppliers, and Valley environmentalists. Each of the Board members, indexed by m, assigns a distinct vector of weights to these constituencies, reflecting a diverse configuration of political affiliations.

Each constituency group's utility in year t, as well as each Board member's personal utility in that year, is a function of the result vector for that year, denoted by $\mathbf{r}_t$, (whenever possible, we suppress the time subscript). Each annual vector has seven components, indexed by j.

(1) Water rights are assumed to rest with landowners, so landowner profits, r_L, are given by:

$$\text{(land used} \times \text{shadow value of land} + \text{water used} \times \text{shadow value of water).}$$

Land used includes both land planted with crops and land actively participating in a fallowing program.

(2) Farming profits, r_F, are given by:

$$\text{(fallowed land payment)} + [\text{(crop production} \times \text{crop price)} - \text{costs}]$$

where the costs include the cost of capital and water used in production, land rental, and water scarcity payments.

(3) Agricultural activity, r_A, is measured by the amount of land in cultivation (i.e., land used but not fallowed).

(4) Employment, r_E, is calculated using a labor multiplier for crop outputs developed by George Goldman and used in the Imperial County Agricultural Crop & Livestock Report.

(5) An index of Imperial Valley environmental quality, r_D, is constructed as a function that increases with Salton Sea elevation and (because of dust issues) decreases with fallowed land.
(6) A measure of other sector activity, r_O, is constructed using Goldman's multiplier for private sales.
(7) Residual transfer revenues, r_R, are given by:

net payments to IID from the bargaining
+ any revenue gain from increased water prices
− (revenue declines from lower water prices + payments for land fallowing
+ system improvement expenditures + irrigation capital subsidies
+ penalties for failing to meet obligations).

Constituency group k has a constant elasticity of substitution (CES) utility function of the form

$$u_k(\mathbf{r}) = \left[\sum_{j=1}^{7} (\alpha_j^k r_j)^{\rho_k} \right]^{\frac{1}{\rho_k}}$$

and Board member m's utility function has the form

$$u_m(\mathbf{r}) = \left[\sum_{j=1}^{7} (\alpha_j^m r_j)^{\rho_m} + \sum_{k=1}^{6} (\beta_k^m u_k(\mathbf{r}))^{\rho_m} \right]^{\frac{1}{\rho_m}}.$$

The α-weights placed by constituency groups and Board members on the result variables are given in Table 2, and the Board members' β-weights on the various constituency groups are given in Table 3. These weights were generated by reviewing local press as well as the public statements and voting records of the individual Board members. After reviewing these documents, the authors selected the weight values based on their collective judgment as to each Board member's primary concerns. IID's total annual utility is the average of the five Board members' utility:

$$u_{\mathrm{IID}}(\mathbf{r}) = \frac{1}{5} \sum_{m=1}^{5} u_m(\mathbf{r}).$$

The stream of annual utilities is discounted by the Board's discount rate δ_{IID}. The present discounted value to the Board of a Salton Sea survival probability π_s given by $u_{\mathrm{IID}}^{\mathrm{SS}}(\pi_s)$, where $u_{\mathrm{IID}}^{\mathrm{SS}}(\,\cdot\,)$ is a concave function. IID's total utility is thus given by

$$U_{\mathrm{IID}}(\mathbf{b}) = u_{\mathrm{IID}}^{\mathrm{SS}}(\pi_s(\mathbf{b})) + \sum_{t=0}^{T} \delta_{\mathrm{IID}}^t [u_{\mathrm{IID}}(\mathbf{r}_t(\mathbf{b}))]$$

As noted earlier, we investigate how the agreement would have evolved had the landowners controlled the District's water rights. We model this by transferring increasing amounts of control to a coalition of landowners and owner/operators, i.e., by

Table 2. Result variable weights.

	Owner profits r_L	Farming profits r_F	Agric. activity r_A	Unem-ployment r_U	Valley envir. r_E	Other sectors r_O	Residual revenue r_R
Constituency groups							
Landowners	0.75	0.05	0.25	0.05	0.05	0.05	0.05
Owners/ operators	0.33	0.33	0.33	0.05	0.1	0.05	0.05
Operators	0.05	0.5	0.4	0.05	0.1	0.05	0.05
Non-Labor Input Suppliers	0.05	0.1667	0.4	0.05	0.1	0.33	0.33
Valley Environmentalists	0.05	0.05	0.2	0.05	0.8	0.05	0.10
Labor and Ethnic Interests	0.05	0.1	0.3	0.5	0.1	0.05	0.5
Board members							
Allen	0.2	0.2	0.1	0.05	0.05	0.05	0.1
Kuhn	0.1	0.1	0.1	0.05	0.05	0.2	0.2
Maldonado	0.05	0.2	0.05	0.2	0.05	0.1	0.1
Horne	0.05	0.1	0.2	0.1	0.1	0.05	0.1
Mendoza	0.05	0.1	0.2	0.2	0.1	0.05	0.2

Table 3. Constituency group weights.

	Landowners	Owner/ operators	Operators	Labor and ethnic interests	Non-labor input suppliers	Valley environ-mentalists
Allen	0.1	0.2	0.2	0.05	0.05	0.05
Kuhn	0.05	0.1	0.2	0.2	0.05	0.05
Maldonado	0.05	0.05	0.2	0.1	0.05	0.2
Horne	0.05	0.05	0.2	0.05	0.1	0.2
Mendoza	0.05	0.05	0.05	0.05	0.1	0.4

increasing the β's corresponding to these groups in the Board members' utility functions. This enables us to estimate the cost to landowners of ceding their rights to a democratically elected Board and how effective the Board was at advancing the interests of the rest of the Imperial Valley community.

Other Water Agencies

In contrast to the IID, the three other water agencies are modeled as homogeneous entities, concerned primarily with maximizing the amount of water they receive and minimizing their expenditures (thus maximizing their revenues). We model each agency's utility as CES; due to lack of information, we assume that each has the same elasticity of substitution. For each year, we calculate water use, w_i, and net budget, nb_i, for agency i.[2]

Net budget is defined as the agency's annual operating budget plus or minus any changes due to the agreement. Finally, MWD wants to maintain its complete control over urban Southern California water. This yields annual utilities for the three agencies of

$$u_{\text{SD}}(\mathbf{b}) = [(\eta_w w_{\text{SD}})^\rho + (\eta_m nb_{\text{SD}})^\rho]^{\frac{1}{\rho}}$$
$$u_C(\mathbf{b}) = [(\eta_w w_C)^\rho + (\eta_m nb_C)^\rho]^{\frac{1}{\rho}}$$
$$u_{\text{MWD}}(\mathbf{b}) = [(\eta_w w_C)^\rho + (\eta_m nb_C)^\rho + (\eta_c wc)^\rho]^{\frac{1}{\rho}}$$

where wc is an index representing MWD's control of urban Southern California water. It increases as the percentage of urban Southern California water provided by MWD increases. The weights η_i reflect the relative importance of water, money and control to the agencies. For agency $i = \{\text{SD}, \text{C}, \text{MWD}\}$, the present discounted value of an agreement vector $\mathbf{b}$ is

$$U_i(b) = u_i^{\text{SS}}\left(\pi_s(\mathbf{b})) + \sum_{t=0}^{T} \delta_i^t u_i(\mathbf{b}\right)$$

where $u_i^{\text{SS}}(\,\cdot\,)$ is the present discounted value of sea survival to agency i and δ_i is agency i's discount rate.

CVWD's leverage in the negotiations rests heavily on the priority system established in the Law of the River. CVWD argued that due to the priority system, IID does not have the right to sell its water to a lower-priority user (San Diego) without CVWD's agreement. So that we can explore the implications of this factor, we include in our model the possibility that CVWD can successfully challenge and void an agreement. The probability of a successful challenge, π_c, decreases with the amount of water transferred to CVWD and increases with the amount of water transferred to San Diego. In the case of a successful challenge, we assume the entire agreement is void and all parties get their default utility. As a result, the final utility each group gets from an agreement vector $\mathbf{b}$ is given by

$$\hat{U}_i(\mathbf{b}) = (1 - \pi_c(\mathbf{b}))U_i(\mathbf{b}) + \pi_c(\mathbf{b})U_i(\mathbf{b}_d)$$

[2] For notational simplicity, we also define a water share for the environmentalist, w_E. This water does not actually flow to the environmentalists, but flows directly to the Salton Sea. We use the notation w_E so that we can continue to index the water allocation vector with i.

where $\mathbf{b}_d$ is default outcome (discussed in detail below). We conduct comparative statics experiments in which we vary the strength of CVWD's legal position with respect to the priority question by changing the specification of the function $\pi_c(\,\cdot\,)$. In the extreme, where IID has an uncontestable right to transfer water to San Diego if it desires, $\pi_c(\,\cdot\,)$ is the zero function.

The State of California

The State of California is concerned with its own financial obligations, the viability of the Salton Sea, and with an efficient allocation of the state's water. Its utility is therefore given by

$$U_{\mathrm{S}}(r_t,\, \mathbf{b}) = u_{\mathrm{S}}^{\mathrm{SS}}(\pi_s(\mathbf{b})) + \sum_{t=0}^{T} \delta_{\mathrm{S}}^{t} \left\{ u(ne_{\mathrm{st}}) + \left[\sum_{i \neq E,S} (\kappa_i w_{it})^{\rho} \right]^{\frac{1}{\rho}} \right\}$$

where the weights, κ_i, represent the state's view of which districts represent the highest-value use of water and ne_{st} gives net expenditures by the state. We sum the water shares only over the water agencies because the state does not receive a direct allocation of water. Moreover, we assume that the state receives no direct benefit of water flowing to the Salton Sea; the state is only interested in the increased survival probability that water may provide.

The Environmentalist

The primary interest of the environmentalist is to ensure a viable future for the Salton Sea, which requires an improvement over the status quo conditions. We therefore define the environmentalist's utility function over the probability of maintaining a viable sea as

$$U_{\mathrm{E}}(\mathbf{r}_t,\, \mathbf{b}) = u_{E}^{\mathrm{SS}}(\pi_s(\mathbf{b})).$$

Implementation of a Bargaining Proposal

In order to construct a mapping from the bargaining space to payoffs, we need to assign to each proposal in this space a vector of IID decisions about how to implement that proposal. We now explain how this assignment is specified. The bargaining will result in net annual payments to IID that must be distributed to parties within the District as well as new restrictions on water use and runoff. To meet the latter two constraints, IID must alter water use within the Valley. The Board can accomplish this either by updating the District's distribution systems or modifying farmers' behavior by affecting their incentives. The IID Board's implementation rule will be modeled as the solution to a two-stage decision problem. In the first stage, IID selects a vector $\mathbf{d}$ consisting of the values of the implementation variables under its control — the price of water, payments for fallowing land, direct water restrictions, subsidization of conservation technology, and expenditures on delivery system improvements. In the second stage, farmers optimize their production decisions. As is usual, the solution is found by solving backwards. First, we characterize the farmers' reaction function to IID's choices and then optimize IID's choices subject to this reaction function.[3]

Farmers' Optimal Production Response

IID is modeled as a single farmer with an 18-dimensional choice set, consisting of the amounts of each of three inputs (land, water, and capital) used in each of six crops (cotton, grain & field crops, market crops, fruit & nuts, low-value crops, and fallowing). When the IID pays farmers based on the number acres they fallow, we can treat fallowing just like any other income-yielding crop. We use a production model developed by Richard Howitt based on the model used to evaluate the Central Valley Project Improvement Act. The model makes a distinction between the water applied to a field (applied water) and that consumed by the crops (evapotranspiration). It holds yield per acre fixed and assumes a constant elasticity of substitution between the ratio of applied water to evapotranspiration and the cost of irrigation. Essentially, a farmer can decrease the amount of water applied to a field by changing his irrigation technology (see Appendix A for a more thorough description of the production model).

The farmers' production function is given by $\mathbf{f}(\mathbf{x})$ and the constraints faced by the farmer are given by $\mathbf{g}(\mathbf{x}) \leq \mathbf{c}$. Input prices are given by $\mathbf{w}$ and output prices by $\mathbf{p}$. The IID Board's choice of a vector $\mathbf{d}$ can affect individual components of $\mathbf{w}$ (the price of water and capital), $\mathbf{p}$ (the price for fallowed land), and $\mathbf{c}$ (the amount of water available to farmers). The farmers' problem is thus

$$\max_{\mathbf{x}} \mathbf{p}(\mathbf{d})'\mathbf{f}(\mathbf{x}) - \mathbf{w}(\mathbf{d})'\mathbf{x}, \quad \text{s.t.} \quad \mathbf{g}(\mathbf{x}) \leq \mathbf{c}$$

We denote the solution to this problem as $\mathbf{x}^*(\mathbf{d})$.

Like any elected body, the IID Board must expect negative repercussions if it institutes a new regime that negatively impacts some of its constituents relative to the status quo. To investigate the implications of these repercussions, we will undertake simulation experiments in which any IID constituency group that incurs a loss as a result of a Board decision is compensated at least partially for its loss.

Constraints on IID's Implementation Problem

We model IID's choice of an implementation vector as a maximization problem subject to three constraints. The first constraint is that farmers will respond optimally to IID's implementation decisions as described above. The second constraint arises from the

[3] We incorporate this feedback mechanism for farmers because farmers control the important variables the Board seeks to influence: crop choice and water use. Our model does not incorporate broader valley outcomes under the control of other stakeholders.

ESA. The Act requires IID to maintain a legally mandated salinity trajectory in the Salton Sea. We compute the impact of changes in Imperial Valley agricultural activity on the Salton Sea using a model derived from the Bureau of Reclamation's Salton Sea Accounting Model, which was used to prepare the Environmental Impact Statement for the WTA. The sea's salinity in a given year depends on both runoff to the Sea in that year and the salinity in previous years. The complete model description is provided in Appendix B. To simplify the notation, we define a function s_t that maps runoff from the IID to sea salinity. Runoff is jointly determined by the difference between applied water and evapotranspiration and the level of system upgrades undertaken by IID. Therefore, we can write $s_t(\mathbf{d}_1, \ldots, \mathbf{d}_t, \mathbf{x}^*(\mathbf{d}_1), \ldots, \mathbf{x}^*(\mathbf{d}_t))$ or $s_t(\mathbf{d}_1, \ldots, \mathbf{d}_t)$. In any year that the sea's salinity level exceeds the mandated trajectory, IID is required to pay a large penalty. The annual salinity limits are given by the vector $\bar{s}$. The penalty paid by IID in year t is thus $\gamma(s_t(\mathbf{d}_1, \ldots, \mathbf{d}_t) - \bar{s}_t)$ where

$$\gamma(x) = \begin{cases} 0 & \text{if } x < 0, \\ x^3 & \text{if } x \geq 0. \end{cases}$$

We can then explore the consequences of a more or less restrictive ESA by varying the level of the penalty. We can also investigate the effect of switching to an ESA that is more cost-benefit oriented by replacing the above fixed penalty structure with one that relates the level of the penalty to the level of the economic damage caused by the infraction.

The third constraint on the IID arises directly from the bargaining outcome. Each bargaining proposal specifies a maximum amount of water that will be available to IID in each year. Since the other parties to the agreement cannot physically enforce this constraint, we model it analogously to the salinity constraint. Let $\overline{W}_t$ represent IID's water allowance in year t. Water usage in IID in response to the implementation vector $\mathbf{d}$ is $W_t(\mathbf{d})$ so the penalty is given by $\gamma(W_t(\mathbf{d_t}) - \overline{W}_t)$ where the function γ is defined as above. Both penalties are subtracted from IID's net transfer revenues in calculating the result variable r_{R}.

IID Optimization

Recall from above that IID's annual utility is defined over a vector of results, $\mathbf{r}_t$. The result variables are induced by an implementation vector $\mathbf{d}_t$. IID's annual utility can thus be written as $u_{\mathrm{IID}}(\mathbf{r}_t(\mathbf{d}_t))$ or $u_{\mathrm{IID}}(\mathbf{d}_t)$. The vector $\mathbf{d}_t$ is chosen to maximize IID's utility subject to a set of constraints that changes in every year prior to b_{R}, the end of the ramp-up period. It follows that $\mathbf{d}_t$ will be distinct in every year prior to b_{R}. The dimensionality of the unrestricted version of this optimization problem is overwhelmingly large. Accordingly, we drastically reduce the degrees of freedom available to IID by imposing the restriction that $\mathbf{d}_t$ must be a quadratic function of time, must agree with the status quo at the start of the ramp-up, must be continuous at the end of it, and must be constant beyond it. That is, we require that for each implementation instrument n, there exist scalars θ_n and ψ_n such that for each t:

$$d_{nt} = \begin{cases} \theta_n t^2 + \psi_n t + C_n & \text{for } t \leq b_{\mathrm{R}} \\ \theta_n b_{\mathrm{R}}^2 + \psi_n b_{\mathrm{R}} + C_n & \text{for } t > b_{\mathrm{R}} \end{cases}$$

where C_n denotes the status quo value of the nth instrument. We can now rewrite IID's optimization problem as

$$\max_{\theta,\psi} u_{\text{IID}}^{\text{SS}}(\pi_s(\mathbf{b})) + \sum_{t=0}^{b_{\text{R}}} \delta_{\text{IID}}^t [U_{\text{IID}}(\theta t^2 + \Psi t + \mathbf{C})] + \sum_{t=b_{\text{R}}}^{T} \delta_{\text{IID}}^t [U_{\text{IID}}(\theta b_R^2 + \Psi b_R + \mathbf{C})]$$

In practice, this optimization problem must be solved using numerical solution techniques. Moreover, since both the farmer response and salinity models are imbedded inside this optimization problem, it is not feasible to incorporate the full version of this optimization problem into the larger bargaining model. To handle this issue, we summarize the IID's response to a bargaining vector in a multi-dimensional response surface. This response surface provides a reduced-form representation of the IID's implementation decisions that can be used to compute bargaining outcomes at the first stage. Stratton *et al.* (2008) discuss the use of response surfaces in the context of a multi-stage simulation model.

Default Scenario

As discussed above, an important component of any bargaining problem is the specification of a default outcome. When modeling a real world negotiation that resulted in an agreement, the modelers typically have few clues as to what would have happened had an agreement not been reached. Moreover, for modeling purposes, what matters is not the counterfactual hypothetical of what actually would have happened had the parties not reached an agreement, but what the negotiating parties *expected* to happen absent an agreement. The present case is somewhat unique however because Interior's actions in the aftermath of the December 2002 failure give us some indication of the implications of negotiation failure. We can use these actions as a guide for constructing default scenarios, with the caveat that their full ramifications cannot ever be evaluated, because the lawsuits that challenged them were never resolved.

It is generally believed that the negotiating parties did not fully anticipate how decisively Interior would respond to a negotiation breakdown. For our purposes, therefore, this response can be interpreted as a shift in the default outcome. Accordingly, we will analyze our model under two different specifications of the default. The first is an estimate of what parties believed would happen in the event of a disagreement prior to December 2002. The second takes Interior's response as a starting point, and assigns probabilities to possible outcomes of the lawsuits that it triggered. We calibrate the model by assuming that under the first default scenario, the parties are unable to reach an agreement while under the second, the bargaining concluded successfully.

We assume that in the event of a disagreement, the values of certain variables in our bargaining space can be predicted with certainty. Since no transfer would occur, all of the variables relating to the transfer — per unit and lump-sum payments, mitigation water and the ramp-up period — are zeroed out with the exception of payments related to the canal lining project. We assume that in the absence of an agreement, MWD would retain the canal lining rights and responsibilities and would thus pay IID and Coachella the necessary sums.

The eventual value of the remaining variables in the event of a disagreement is uncertain. There are four basic issues to address: (1) whether California will receive additional surplus water (the so-called "soft landing"); (2) the division of Salton Sea liability; (3) the division of California's basic 4.4 maf allotment; and (4) the security of IID's water rights. We hypothesize that the resolutions of the first two issues are independent of one another and of the remaining issues. That is, we treat the first two issues as independent random variables. The last two issues are interconnected. One possible resolution of the third is that Interior might drastically reduce the amount of water available to IID as it attempted in early 2003. If Interior were successful in doing so, IID would be likely to install conservation technology and its remaining water right would be far more secure. If the default outcome were that IID preserved its status quo share, the challenge to its rights would be successful with much higher probability.

Figure 3 provides a schematic of the possible default outcomes. The event tree applies to both the initial and the post-December 2002 defaults; however, the probabilities μ_1, μ_2, and μ_3 change. In particular, post-December 2002, μ_1 goes to zero, while both μ_2 and μ_3 decrease. It is important to emphasize that although there is a connection between the expected amount of Salton Sea liability and the allocation of water to IID and CVWD, there is no reason to expect that the division of that liability is related to the water division, absent an agreement.

The possible water and liability outcomes are given in Table 4. The two water outcomes represent the status quo and Interior's proposed re-allocation following the December 2002 failure. We assume that absent an agreement, San Diego, CVWD, and MWD would

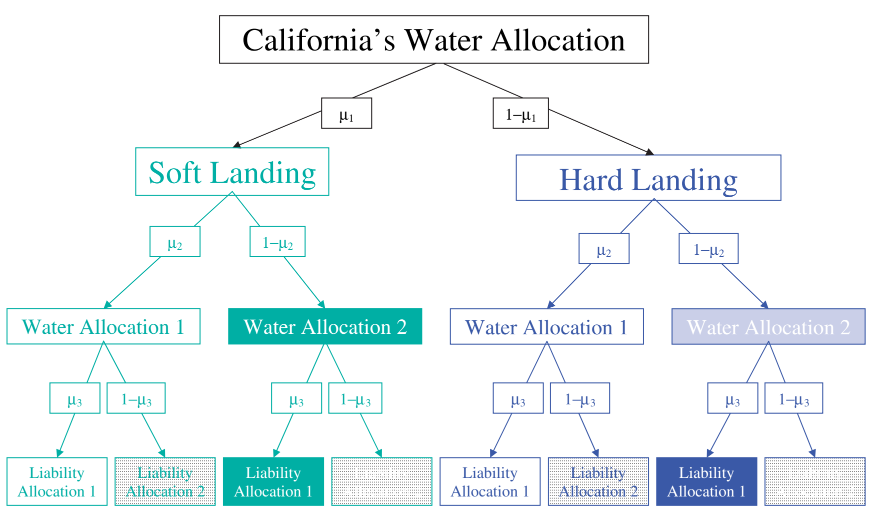

Figure 3. Default scenarios.

Table 4. Default scenarios.

	Outcome 1 (Status Quo) Prob β	Outcome 2 (Interior's 2003 Allocation) Prob $(1-\beta)$
Water division and right security		
San Diego's share	0.000	0.000
IID's share	0.705	0.629
CVWD's share	0.047	0.079
Combined Share of PVID, Yuma, and Native American Tribes	0.099	0.099
MWD's Share	0.149	0.193
Salton Sea liability division		
	Outcome 1 Prob γ	Outcome 2 Prob $1-\gamma$
IID	0	1
San Diego	0	0
MWD	0	0
Coachella	0	0
State	1	0

Reference: Complaint for injunctive and declaratory relief, 2003

not have any Salton Sea liability exposure. In early 2003, a bill was introduced in the California legislature to make IID liable for Salton Sea damage in the event that Interior forced a reduction in IID's water use. For this reason, we include the possibility that IID may be liable for any damages and increase the probability of this outcome in the post-December 2002 default scenario.

Finally, in all default scenarios, the parties are expected to face significant legal costs to litigate issues that would otherwise have been settled as part of the negotiated agreement.

CONCLUSION

In this paper we have developed an analytic framework to address how property rights impacted the WTA negotiations. Using the Rausser–Simon multilateral bargaining model (Rausser and Simon, 1999), we will conduct numerical simulations designed to address the question raised in the paper about how the agreement might have changed if these rights had been allocated differently, or specified in different ways. The answers we obtain will provide insights into the complex interactions between property rights and bargaining problems. The property right issues that arose during this negotiation are not unique to this particular transfer and the pressure to shift water allocations from agricultural to urban and/or environmental uses is not confined to Southern California.

The general framework presented here can be adapted to a variety of other situations. By their nature, water allocation negotiations in particular, and resource allocation problems more broadly, involve many layers of economic decision-making and feedback loops between economic choices and ecosystem responses. An important step in the analysis of any such problem is the creation of a schematic like Figure 2, mapping out the critical pathways between different systems. This process facilitates the development of a consistent and logical structure into which all relevant interactions must be incorporated.

This paper also advocates the use of response surfaces to make it possible to solve negotiation model incorporating multi-stage decision-making. For many water allocation problems, analysts must either adopt numerical solution techniques or sacrifice realism and simplify their representation of the real-world system enough to enable closed-form solutions. The response surfaces provide approximate descriptions of the simulation model's response in the same fashion that closed-form solutions provide an exact description of the analytical model's response. The response surfaces thus mitigate the loss of tractability imposed by using numerical modeling.

Our framework also highlights the critical role that property rights play in water allocation problems. Moreover, our analysis is designed to offer insights into how changes in the definition and security of property rights might influence negotiated outcomes. This is a critical issue in many water issues. For instance, as Goodhue *et al.* (2010) argue, negotiations over the future of the Sacramento-San Joaquin Delta in California are heavily influenced by concerns about the strength of Endangered Species Act protections and the security of existing water rights in Northern California.

As the largest water transfer in history, the San Diego — Imperial Valley WTA is bound to have a huge influence on future water negotiations across the Western United States in the coming years. A more thorough understanding of how specific provisions of this agreement are related to the allocation and specification of property rights may help future negotiators reach more efficient agreements.

APPENDIX A: PRODUCTION MODEL

The CVPM model and the adaptation used in this paper both use a technique known as Positive Mathematical Programming (PMP) developed in Howitt (1995). PMP models work by assuming that farmers are behaving optimally today and using this information to calibrate production functions, which can then be used to extrapolate behavior at different conditions. The technique can be used with a broad variety of production function specifications.

The model used in this paper was developed by Richard Howitt as a simplification of Stephen Hatchett's CVPM model. Both models focus on the trade-offs between irrigation technology and water applied. They assume a constant elasticity of substitution between total irrigation costs and the ratio of water applied to water actually consumed by the crops. Yield and non-irrigation inputs are held constant per acre. Farmers then choose how much land to plant in each crop and the most cost effective combination of applied water and irrigation technology. In the simpler model used here, prices of inputs and outputs are taken as given. Costs per acre do increase as more and more of a specific crop is planted. The total non-irrigation cost per acre is given by $\alpha_i + 0.5\gamma_i x_i^{\text{land}}$ where α_i and γ_i are determined during the calibration process and x_i^{land} represents the total acres planted in crop i.

Let y_i refer to the base yield per acre of crop i, x_i^{land} refer to the amount of land planted with crop i, x_i^{water} the **per acre** amount of water applied to crop i, x_i^{capital} the amount of irrigation capital used **per acre**, w_j the price of input i, and p_i the price of output i. The farmers' problem is then

$$\max_{\mathbf{x}} \pi(\mathbf{x}) = \sum_{i=1}^{6} [p_i y_i - (\alpha_i + 0.5\gamma_i x_i^{\text{land}}) - x_i^{\text{wat}} w_{\text{wat}} - x_i^{\text{cap}} w_{\text{cap}}] x_i^{\text{land}}$$

subject to

$$\sum_{i=1}^{6} x_i^{\text{land}} \le \bar{x}^{\text{land}}$$

$$\sum_{i=1}^{6} x_i^{\text{wat}} x_i^{\text{land}} \le \bar{x}^{\text{wat}}$$

$$A_i \left[B_i \left(\frac{x_i^{\text{wat}}}{\text{evap}_i} \right)^{\rho_i} + (1 - B_i)(x_i^{\text{cap}} + x_i^{\text{wat}} w_{\text{wat}})^{\rho_i} \right]^{\frac{1}{\rho_i}} = 1$$

$$-(x_i^{\text{wat}} - \text{evap}_i) \le 0$$

The production function constraints do not apply to the sixth "crop" — fallowing — because the "production function" for fallowed land is simply $y_{\text{fallow}} = x_{\text{fallow}}^{\text{land}}$.

APPENDIX B: SALTON SEA SALINITY MODEL

The salinity model used in this paper is a reconstruction of the Bureau of Reclamation's (Reclamation) model, based on documentation included in the EIR/EIS. The model uses Monte Carlo simulation to estimate the mean and variance of salinity trajectories based on changes in IID runoff into the sea. The sources of randomization in this model are independent of the transfer. They are derived from natural fluctuations in water flows from year to year and from scientific uncertainty about salt precipitation patterns. The year-to-year impacts of IID runoff changes on Sea salinity are modeled as deterministic.

As part of the modeling process, Reclamation projected inflows and salt load (i.e., the amount of salt in those inflows) to the Salton Sea from IID, Coachella, and Mexico over the next 70 years assuming no water transfer. Their methodology assumes that if no transfer is implemented, future flows will be similar to past flows. Hence, they create a distribution for future inflows from IID by randomly selecting a past value. Water inflows and salt load were sampled jointly from this distribution to maintain hydrological consistency.

Essentially, the model works by keeping track of the total water and salt in the Sea. The basic equations of the model are

$$\begin{aligned}
\text{salinity}_{it} &= \frac{\text{salt}_{it}}{\text{water}_{it}} \\
\text{salt}_{it} &= \text{salt}_{i,t-1} + \text{BaseSalt}_{it} + \Delta\text{IIDSalt}_t + \Delta\text{CoaSalt}_t - \text{SaltPrecip}_{it} \\
\text{water}_{it} &= \text{water}_{i,t-1} + \text{BaseWat}_t + \Delta\text{IIDWat}_t + \Delta\text{CoaWat}_t - \text{NetEvap}_{it} \\
\text{SurfaceArea}_{i,t-1} &= f(\text{water}_{i,t-1}) \\
\text{NetEvap}_{it} &= \text{SurfaceArea}_{i,t-1} * (\text{EvapRate}_{it} - 2.5) \\
\text{EvapRate}_{it} &= 70.5 * 1 - 1.21 * 10^{-6}\text{salinity}^2_{i,t-1} - 5.91 * 10^{-5}\text{salinity}_{i,t-1}
\end{aligned}$$

where t indexes time and i indexes a given iteration of the Monte Carlo simulation. BaseWat_{it} and BaseSalt_{it} represent the no transfer total inflows of water and salt, respectively. As discussed above, BaseWat and BaseSalt are randomized but Δ IIDWat and Δ IIDSalt are not. The same is true with the Coachella changes. A table produced by Reclamation gives the function f relating water quantity to surface area of the Sea. The variable SaltPrecip_{it} refers to the process by which salts precipitate out of the Sea forming solid deposits. There is much disagreement over the exact rate at which this occurs so Reclamation drew a value for each year from a uniform distribution over the interval 700,000 to 1.2 million tons per year.

Unfortunately, Reclamation only modeled scenarios where CVWD gets no water from IID and where they receive 100 kaf per year. To model other scenarios, we use straight-line interpolation between the two points we have. The primary reason for transferring water to CVWD is to replenish that District's aquifer. As a result, we model the runoff from CVWD to the Salton Sea as a function of the total amount of water transferred to CVWD.

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