Water Scarcity and Outcomes of Indigenous Claims to Water in the American West

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ABSTRACT

Surface water in the American West is fully allocated, and water use is projected to exceed supply by 2030. A growing source of uncertainty in bringing the region's human and ecological systems into balance is that 170 of 226 American Indian reservations have unresolved claims to water. We use an economic framework to analyze a novel and complete dataset on settlement agreements for previously resolved reservation water claims. We show that tribes on reservations undertake the settlement process only when the economic value of water is high, and they face physical water scarcity. When more users are involved in the negotiations, settlement is delayed, increasing water insecurity and ecological damage. We use our findings to predict allocations for 24 ongoing water right negotiations, resolving a key uncertainty. Given the large volume of water allocations they hold, tribes will be key to the sustainable management of water in the American West.

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INTRODUCTION

Competition over limited water resources is a defining characteristic of the American West, where population growth, climate change, and persistent drought exacerbate the gap between water supply and demand (1–3). Sustainable water management in the West requires changes in the pattern and overall level of water use to reconcile growing urban demands with supplies that are becoming more variable at scales ranging from small streams to the Colorado River itself (4–6). The recognition of Native Americans' long-neglected—and often substantial—water rights looms large in the future of water in the West because satisfying these claims could entail major changes in distribution of water rights (7).

Surface water in western states is governed by the prior appropriation doctrine, which assigns water rights based on the timing of the initial claim. This "first in time, first in right" allocation of water mandates that in times of shortage, senior water claims are fully satisfied before junior claims are filled. However, surface water rights in the American West were appropriated without regard to the needs of American Indian reservations (8–10). By the mid-1900's, most streams had been fully allocated and dammed, diverted, and appropriated for energy, mining, and urban development (8,11,12). As off-reservation water use exceeded the limits of natural system sustainability, tribal water availability became highly constrained and uncertain. For example, the Soboba, San Luis Rey, and Tohono O'odham reservations in the Southwest all saw acute water scarcity after off-reservation diversions reduced ground or surface water supplies used for agricultural production (13–17), while the Yakama and Pyramid Lake Paiute reservations saw culturally and economically important fisheries affected by off-reservation irrigation diversions (18–21).

In 1908, the US Supreme Court (Winters v. United States) ruled that tribes have high-priority water rights "sufficient to fulfill the need of the reservation as a homeland" (22). The ruling affirmed the federal government's trust responsibility to provide tribes with water rights, but did not grant appropriative rights or establish metrics to determine what quantity of *Winters Rights* tribes should receive. Because Native American water rights were not included in initial western water allocations, there is ongoing conflict between existing water users and contemporary Winters Right claims (23). The National Water Commission acknowledged in 1973 that by neglecting to file claims to water rights on behalf of tribes at the time reservations were created, the federal government precluded tribes from cultural, environmental, and economic benefits of water right security (23). Yet since the original ruling in 1908, only 56 of 226 federally recognized reservations in the western US have settled Winters Right claims.

To this day the most commonly cited estimate of the potential amount of Winters claims of 45.9 million acre-feet per year comes from a rough estimate made in 1983 by the Western States Water Council (24). Comparably, the entire Colorado River, which is diverted to such an extent by seven arid western states that its waters no longer regularly reach the Gulf of California, provides just over 15 million acre-feet annually on average (25).

Despite the potentially massive impacts of tribal water claims, the process that determines the outcomes of such claims is not well-understood. Up to this point, a more thorough analysis of Winters adjudications has been limited by a lack of contemporary and historical reservation-level socioeconomic and environmental data. Womble et al. (2018) quantify the approved and proposed adjudication agreements, but do not quantify the water resources under dispute, examine the outcomes of ongoing adjudications, or examine the determinants of adjudications or the duration of negotiations (7). Deol and Colby (2018) compare a cross-section of 51 reservations using USDA and US Census data from 2010 and 2015 to show that reservations with adjudicated Winters Rights appear to be stronger economically and agriculturally, but do not explore the determinants of adjudication across the full set of western reservations. (26).

To fill this gap, we compile an extensive longitudinal dataset from historical documents, settlement agreement texts, historical geospatial land and water use data dating back to the 1970's, government reports, and surveys of reservation-level socioeconomic characteristics (27,28). To analyze these data, we adopt the economic framework developed Ayres, Edwards, and Libecap (2018) for studying the adjudication of groundwater rights.

Our empirical analysis proceeds in three steps. First, we test for factors that increase a reservation's likelihood of initiating adjudication—*model 1* (29). We then examine adjudication costs, known as transaction costs, which may impede settlements—*model 2* (30). Identifying common adjudication catalysts (e.g. water scarcity; agricultural goals) and barriers to agreement from these models allows us to estimate the expected volume of tribal water entitlements allocated to each tribe—*model 3*.

Resolving Winters Rights is critical to the cultural, economic, and ecological survival of American Indian reservations. When tribes lack legal mechanisms to protect their water, unregulated water use may deplete reservation streamflow, aquifers, and springs. The resolution of a Winters claim currently lasts an average of 21 years. The complete set of adjudication start and resolution dates are shown graphically in figure 1. During this time, water users continue depleting streamflow and groundwater resources, causing economic losses and potentially doing irreversible damage to reservation ecosystems. Thus, while understanding the outcomes of adjudications themselves is important, so too is understanding the causes of delay and discord, and how they can be overcome to reduce losses incurred due to delay.

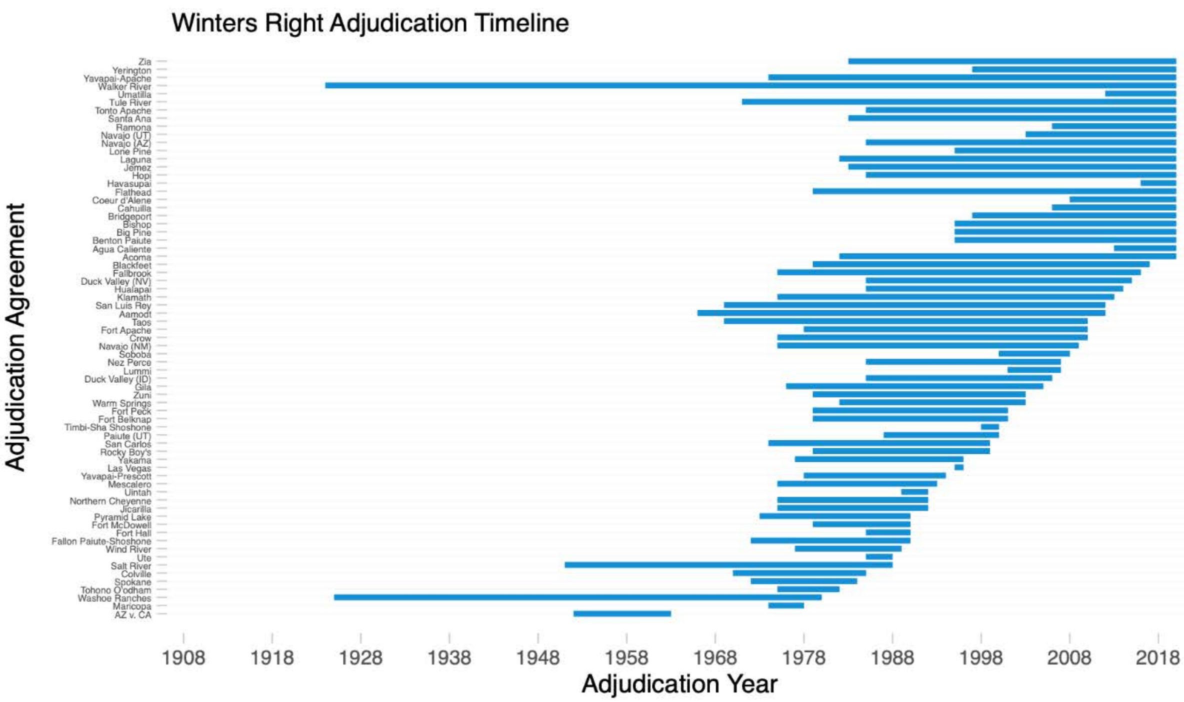

Figure 2. *Timeline of Winters Rights adjudication negotiations and resolutions. Blue bars begin at date when adjudication effort begins and end when ratified. Bars extending to 2019 are ongoing.*

This paper contributes to the literature on sustainable water management in three ways. First, we use our findings to predict the expected allocations of ongoing Winters right negotiations, which are a key source of uncertainty in water management in the American West. Second, we provide insight into the resolution of indigenous claims to water, which are a key issue in the management of water rights throughout the world, including Chile and Australia (31–33). Third, analysis of the resolution of Winters rights is highly relevant to understanding the resolution of conflict over water broadly, which is an increasingly important issue in arid regions (34).

WINTERS RIGHTS NEGOTIATIONS

Winters rights are adjudicated either via a court decree achieved through litigation or a negotiated settlement agreement. Negotiated settlements, the most prevalent adjudication strategy, typically result in a combination of water entitlements and federal funding for tribes. Tribes can pursue Winters rights by filing breach of trust claims against the U.S. government for damages they incurred when the government—which holds tribal lands and resources in trust—neglected to claim water on tribes' behalf after the initial 1908 Winters ruling. If these claims are found to have merit, the federal government is legally bound to assert claims to water for tribes, assist tribes in resolving these claims through litigation and negotiation, and support settlement implementation.

Ayres, Edwards, and Libecap (2018) develop and economic framework to study the adjudication of previously unquantified groundwater rights. Their approach first examines the likelihood of adjudication, finding it is increasing in the benefits to users. Then, they examine the role of contracting costs, defined as costs "that arise during private bargaining to redefine ownership arrangements as well as efforts to define the resource's extent and characteristics (17, p.47)." Their results show that where contracting costs are high, agreements are delayed or never reached (30). We adapt this approach to the institutionally similar process undertaken by tribes and off-reservation water users in a basin during a Winters claim.

Generally, parties participate in an adjudication when their expected benefits from doing so exceed their costs. Physical water scarcity and the corresponding growth in the value of water, as in other resources, may increase the benefits of resolving property right claims (35). The value of surface water increases where precipitation and streamflow are scarce (27,36). Tribes benefit from legally defining their priority rights to water because they acquire the ability to generate income from water through sales, leases, or productive use (37). For example, after settlement the Navajo Nation in New Mexico developed the Navajo

Agricultural Production Industry and the Gila River Indian Community earned $97.5 million per year leasing 18,000 acre-feet of water (38). Similarly, off-reservation right holders participate in negotiations to resolve looming uncertainty about how Winters rights will be accommodated (i.e. from which appropriative rights holders), or to avoid being litigants to proceedings in state courts (27).

Agreement may prove elusive even when the net gains from settlement are positive for the basin as a whole (4,32). Some users who do well under the status quo may oppose agreement, and the costs to bring them on board may be high (39–41). Increases in the number and heterogeneity of bargaining parties tend to increase the transaction costs of negotiation and make agreement less likely (42–46,27), although this is not always the case (47,48). Heterogeneity in the marginal product of water, such as between reservations and urban water users, influences the power dynamics and bargaining positions of adjudication parties (49).

Conflicting bargaining positions arise from different perceptions of fairness and from information asymmetries (36,28). If the legal outcome of cases is not clear because of limited precedent, opportunities for agreement may be reduced. For example, the Walker River Irrigation District in Northern Nevada has effectively delayed quantification of the Walker River Paiute Tribe's water rights for almost 95 years through litigation in Nevada state courts (50). Off-reservation appropriators argue that the legal seniority of their water rights should be maintained, whereas tribes argue that appropriators have no inherent right to water, but rather have benefited from free use of the tribes' water (51). Federal funding in negotiated settlements can help to defray high contracting costs and facilitate agreement, for instance in Arizona, negotiated settlements have included compensation for irrigation districts that forfeit water to satisfy newly defined Winters Rights (52).

METHODS

The study focuses on 226 federally recognized reservations in the 11 arid western states that use the appropriative rights doctrine, as shown in figure 1. Eighty-one reservations have initiated the process of adjudicating their water rights. Of these, 56 reservations have resolved their Winters claims—44 through negotiated settlements and 12 through state court decree. We treat Navajo Nation and Duck Valley Indian

Reservation as distinct reservations in each state they overlap because they must pursue separate adjudications in each state. We construct a binary variable indicating whether a tribe has initiated adjudication. All variables used in the statistical analysis are described in A1 and summary statistics are provided in A2.

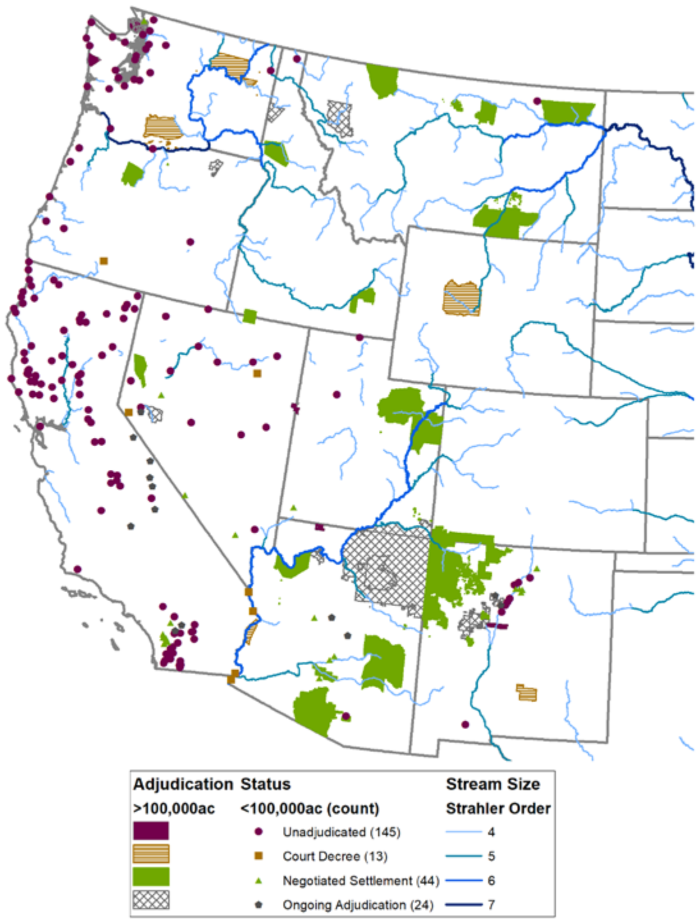

Figure 2. *Adjudication status of western reservations. Reservations under 100,000 acres are represented as symbols while those over 100,000 acres are represented according to reservation acreage. Navajo Nation and Duck Valley Reservation span multiple states, and their adjudication status is provided separately for each state.*

Using the full sample of 226 reservations, we test for the probability of a reservation having initiated the Winters adjudication process as a function of underlying determinants of adjudication benefits: *prime agricultural acres*, the amount of land that irrigation water could be put to agricultural use on-reservation; highest *stream order*, a measure of water resource size; off-reservation *population growth*, a key measure of water value over time; *point-of-diversion density*, a measure of resource scarcity; and *precipitation*, a measure of water scarcity. In *Model 1*, the probability of entering into the adjudication is modeled as a function of these reservation-level characteristics. We run logistic and linear regressions of current adjudication status on these variables, which are either time-invariant or constructed to measure conditions prior to the start of adjudication.

Next, we test for factors that increase the duration of the legal resolution of Winters claims by focusing on reservations that have completed an adjudication. We construct a second dataset for 44 adjudication agreements that have resolved Winters claims for 56 reservations. Primary data on negotiated settlement agreements, settlement terms, bargaining parties, water entitlements, and federal funding were collected from individual settlement texts housed at the University of New Mexico's Native American Water Rights Settlement Project. We collected primary data on litigated adjudications from State and District court filings and from the Indian Claims Commission Decisions housed at the Oklahoma State University Library. In *Model 2*, we use a Cox Proportional Hazard Model (CPH) to perform a duration analysis to test the effect of covariates *number of bargaining parties, number of unique bargaining party types, Democratic congressional majority,* basin *precipitation variance*, and 1980 county-level *urban land cover*.

Finally, we assess the distribution of outcomes of 36 negotiated settlements to the 44 reservations included in those agreements and create a prediction of pending adjudications in *Model 3*. We assess two outcomes—water entitlements and federal funding—as functions of characteristics of the bargaining problem faced by the tribe and other basin users. The ultimate distribution of a tribal water entitlement as defined in each adjudication agreement is measured as the annual volume (acre-feet per year) of non-consumptive water rights assigned under the agreement. Total federal funding for each adjudication settlement is recorded from individual negotiated settlement acts and is adjusted for inflation to 2010$. We test the covariates *prime reservation acres; farmed reservation acreage (1974); off-reservation county population growth rate in the decade prior to resolving claims; year when settlement is finalized; adjudicated reservation area within a state as a percentage of state area; and Democratic congressional* *majority*. Using a slightly modified group of dependent variables optimized for prediction, we then run a linear regression model that we use to predict outcomes to pending adjudications.

RESULTS

Water Scarcity Drives Adjudications

We first run model 1 to test the relationship between adjudication benefits and the probability the adjudication process is initiated. The results are summarized in table 1 and full statistical results are provided in A3. The results show that the probability of pursuing adjudication increases when the value of water rises through a combination of increasing demand and constrained supply. Mean precipitation is negatively and significantly correlated with the probability of a reservation having initiated adjudication in some specifications (r.1 of table 1). Less precipitation is indicative of water scarcity, which increases the relative value of water. Similarly, point-of-diversion (POD) density is positively correlated with adjudication. Both results suggest reservations are more likely to adjudicate when water is scarce.

Table 1. *Results of the analysis of tribal water adjudications. An increase in each characteristic increases, decreases, or has an ambiguous effect on the likelihood of a reservation entering into adjudication.*

Outcome	Result	Economic or Environmental Characteristics	Result
	All Agreements		
Likelihood of Adjudicating	1	Water supply constraints (*POD density*, *lack of precipitation)*	Increases
	2	Competing water demand (*population growth)*	Increases
	3	Potential ag demand (*prime reservation acres)*	Increases
	4	Resource size (*stream order)*	Increases
	Adjudicated		
Years to Resolve	5	Contracting costs (*number of parties)*	Increases
	6	Group heterogeneity (*precipitation; land use; types of bargaining parties)*	Ambiguous
	Settled		
Water Entitlement	7	Ag capacity (*prime farm acreage; farmed reservation acreage)*	Ambiguous
	Settled		
Total Funding	8	Ag capacity (*prime farm acreage; farmed reservation acreage)*	Increases
	9	Federal factors (r*esolution year*, *Democratic Congressional majority)*	Increases

Population growth rate prior to adjudication start is positively correlated to the probability of tribal adjudication (r.2 of table 1). As populations grow, water demand increases, as do the expected benefits of adjudication. All else equal, reservations with higher prime farm acreage are anywhere from up to twice as likely as their counterparts to pursue adjudication (r.3 of table 1). Likewise, higher order streams are also positively correlated with adjudication (r.4 of table 1). Greater farm acreage and larger streams are key variables determining the volume of water per dollar of fixed adjudication costs. Results on the decision to adjudicate are summarized in figure 3.

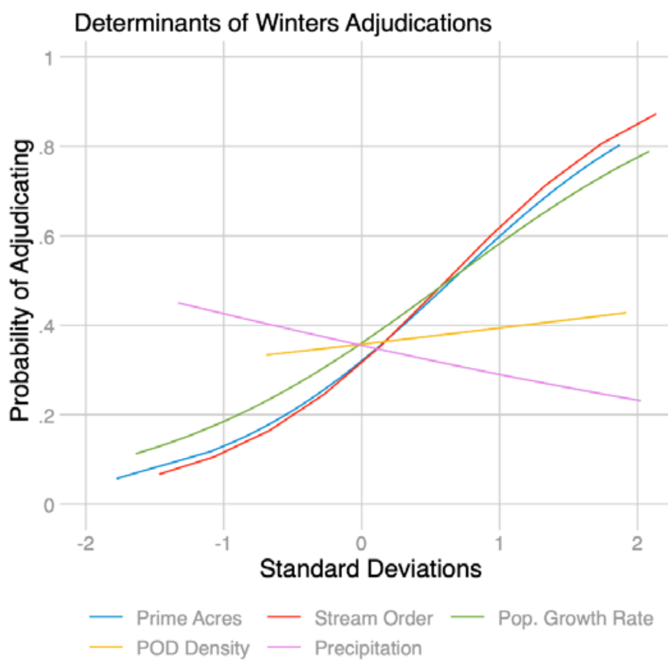

Figure 3: *Predicted change in probability of a tribe undertaking adjudication for standardized changes in a given explanatory variable about its mean; all other variables are held at their means; specifications for these results are shown in table A3-1, column 1.*

Contracting Costs Lengthen Negotiations

We test the relationship between the duration of negotiations and predictors of high contracting costs; results are shown in A4. Despite the small number of observations, we observe statistically significant results across model specifications: an increasing number of bargaining parties is highly correlated with a more protracted adjudication process (r.5 in table 1). We also test for the effect of heterogeneity among bargaining parties using three measures: spatial precipitation heterogeneity, land use heterogeneity, and heterogeneity in the types of bargaining parties (r.6 of table 1) but find ambiguous results. The top-right panel of figure 4 shows the Kaplan-Meyer plot of type of bargaining party. In contrast to the results for number of bargaining parties, it is not clear that more *types* of parties lengthen negotiations, and these results are confirmed in the regression models. Similar plots for the first two measures of heterogeneity are shown in A4. We also find suggestive evidence that a higher percentage of years of Democratic congressional majority leads to a more expedited adjudication process. This finding is supported by anecdotal accounts of tribes waiting to have settlements ratified by a Democratic congress and suggests the key role government financing plays in facilitating agreement.

Predicted Outcomes of Ongoing Adjudications

We use a regression model to analyze the outcomes of completed negotiated settlement agreements, utilizing similar covariates as in the CPH models (see A5). The bottom-left panel of figure 4 shows the water and funding settlement amounts for each reservation, ordered by total settlement amount. Our results suggest that prime reservation acreage and farmed reservation acres in 1974 consistently and significantly predict larger water entitlements and larger levels of total adjusted federal funding per negotiated settlement (r.7-8 in table 1). Water entitlement volumes appear to primarily be a function of a reservation's capacity to farm, while additional factors related to the role of federal money explain the level of settlement funding. Over time, federal funding for settlement agreements has increased, and federal funding increases when Democrats hold a majority in both houses of Congress (r.9 in table 1).

We develop a second model of outcome determinants calibrated to most accurately predict the water entitlement outcomes of all remaining adjudications, placing particular emphasis on the 24 pending adjudications (A5-3). Figure 4, bottom-right panel shows the predicted outcomes, in red, along with actual negotiation outcomes relative to the amount the model predicts, in blue. Prediction point estimates should be interpreted with caution because there is no established rule for quantifying tribal water allocations, and each negotiation has a considerable amount of idiosyncrasy that affects outcomes. Predictions results are shown in A5, where we provide the 95% confidence interval around the mean settlement prediction. The total prediction of 1.0-4.7 million AF is considerably less than the commonly cited number of 45.9 million acre-feet annually (24).

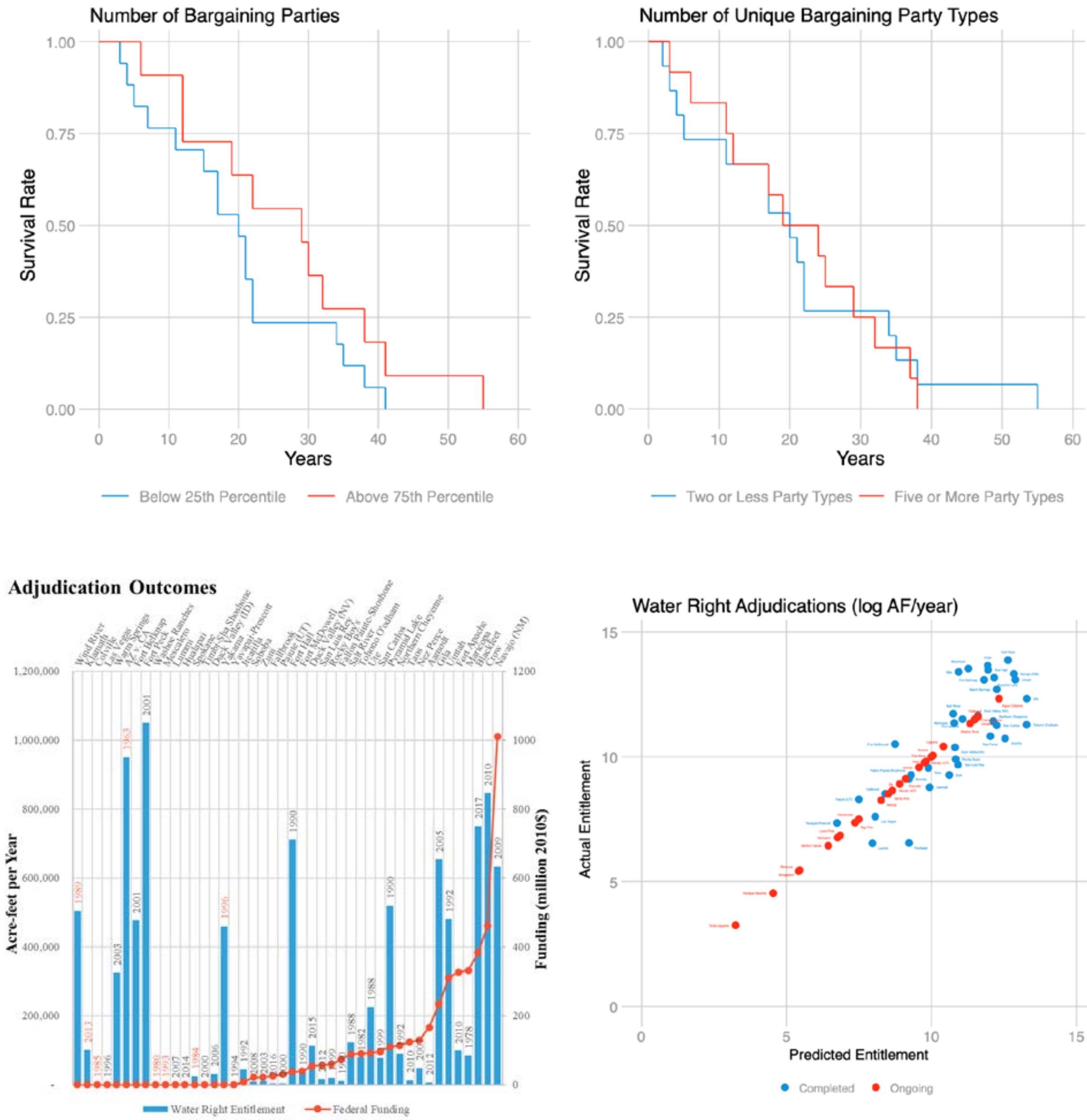

Figure 4: *Top-Left - Kaplan-Meyer nonparametric estimate of the survival function for the upper and lower quartile of adjudication number of bargaining parties. Top-Right – Kaplan Meyer nonparametric estimate of the survival function for two subsamples of number of types of bargaining parties. Agreements can have a maximum of 6 types of bargaining parties. Parties are categorized as reservations, state and federal government, irrigation districts, urban water providers, individuals, and other. Bottom-Left – Tribal water adjudication outcomes in terms of water entitlement (blue) and federal funding (red); date of adjudication agreement is black if a negotiated settlement and red if court decree. Bottom-Right predicted versus estimated water right entitlement outcomes of Winters adjudications (blue) and predicted outcomes of ongoing adjudications (red).*

DISCUSSION

This article provides new insights about the physical and economic context in which legal disputes over water rights arise. These insights are important because the resolution of indigenous rights to water is not unique to the United States. In Chile and Australia, water rights to indigenous groups were not initially allocated (31–33). In both countries, indigenous groups received land titles without appurtenant water rights. In Australia, indigenous land exceeds 30% of the country's land base, while indigenous water rights are estimated at less than .01% of total water allocations (31). Long-term impacts include corresponding damages to fisheries, land subsidence, water quality, local economies, and public health (53–56).

We find that tribes are more likely to assert claims when physical water availability is limited, competing demand for water grows, and the relative value of water rises. Tribes are also more likely to pursue adjudication when the amount settlement is expected to be large, overcoming the costs of negotiating. However, high contracting costs deter users from asserting legal claims until water scarcity is severe, delaying the resolution of competing demands, lengthening unstainable resource use, and potentially causing irreversible ecological damage.

After asserting claims, many tribes have faced lengthy adjudications, which suggests that reservation populations and ecosystems will continue to endure water shortages for years. Hence, contracting costs that slow the adjudication process amplify the impacts of water scarcity on public health, tribal economies, and the environment. Anecdotes describing tribes' experiences of water scarcity include depleted wells for irrigation and household drinking water as well as streamflow depletion that collapses fisheries (13,16,57–59). Winters adjudications typically begin in state courts prior to negotiation, and litigation involves more parties because of legal requirements to involve all water users in the basin. The mean adjudication lasts in excess of 21 years, and our work provides insight into reducing the duration of the process. Once a tribe begins to pursue a negotiated settlement the number of parties typically falls.

Because we find high numbers of users delay settlement, opting to negotiate earlier in the adjudication process may reduce the overall duration—and costs—of resolving Winters claims (18,60–62).

Even as off-reservation agricultural water use is declining (63), the incentives provided by Winters may steer reservation economies *towards* agriculture because Winters claims, entitlements, federal funding, and settlement infrastructure are premised on and provided to support the pursuit of agriculture, and settlement agreement funding is often targeted at agricultural water delivery infrastructure (64–67). Given that agriculture is an inherently water-intensive activity, tribes can improve their bargaining positions by asserting Winters claims based on the amount of irrigable acreage on a reservation, or on plans to develop reservation agriculture. This dynamic potentially pushes tribes toward less sustainable water use in a landscape where managers are focused on moving water use out of agriculture to urban and environmental uses (68,69).

This study sheds new light on tribal water adjudications to the point of settlement, but more work is needed to understand what happens to land use and economic development on reservations after signing an adjudication agreement. Winters settlements could lock tribes into low-value agricultural production or provide funding and resources to build a robust agricultural economy. Tribes may use water to provide ecosystem services and increase the sustainability of water systems (7), or Winters Rights may move off-reservation via leases to users who have more capacity to place the water in high-value uses (70). The leasing of tribal water rights can create beneficial income streams, but has also been characterized as another pathway for tribally-owned resources to be consumed off reservation (71).

This paper relies on several key assumptions. First, the statistical analysis is primarily based on statistical correlations; causal estimation is difficult in this setting. While we have tried to include measures leading to but not affected by adjudication in our analysis, the analysis is potentially susceptible to omitted variables that could cause dependent and independent variables to only appear to have the expected relationship. Second, our analyses have a limited number of observations, especially when focused on the subset of reservations that have settled. However, we emphasize that our dataset comprises the entire population of Winters-eligible reservations, so the results we report are population averages rather than sample statistics. Third, an important assumption in our predictions is that future water right settlements will tend to be determined by the same factors as past settlements. However, because there is no definitive rule for Winters adjudications, this will not necessarily be the case (72).

With these limitations in mind, our results suggest that the future impact of unadjudicated Winters rights for off-reservation users may not be as severe as anticipated. The largest reservations, poised to receive the most water, have already adjudicated. As such, previous estimates of unresolved claims to Winters Rights, based on early negotiated settlements, overstated the entitlements that tribes have subsequently received. We find that the only reliable predictor of water allocations is farming capacity, how much agriculture the tribe undertook in 1974, or prime farm acreage, which is fixed for each tribe. Thus, although many tribes still have "implicit" rights to water, the amount of water that will ultimately result from these claims is likely much smaller than is often assumed. While this may be good news for policymakers and water managers, it underscores the enduring negative impacts of reservation-era policies for tribes who now have limited prospects for securing substantial water rights.

However, this does not mean Winters settlements have not been beneficial. They have generated opportunities to implement water marketing activities to address shared water shortages, potentially bringing stressed natural systems into more sustainable use, and offering lessons that could be applied elsewhere. For instance, both Chile and Australia have water marketing frameworks in place (32,73,74). In a recent example, the Gila River Indian Community (GRIC) will lease 200,000 acre feet to the Arizona Water Banking Authority in 2019 and 2010 as part of the Lower Colorado River Drought Contingency Plan to maintain lake levels in Lake Mead (75). Going forward, the leasing of adjudicated Winters rights offers revenue for tribes and the potential for water managers to address ecological and urban water shortfalls.

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APPENDIX

A1. DEFINITION OF THE VARIABLES

Water Demand:

Prime Farmland: We construct an exogenous measure of prime farmland acreage on reservations, using spatial data on soil quality, as a proxy for Practicably Irrigated Acreage (PIA). We use the Schaetzl soil index, an ordinal 21-point soil productivity index (PI), which ranks soil productivity based on soil taxonomy and structural characteristics rather than on nutrient or water content, and is exogenous to differences in irrigation and farm management across reservations over time (76). We adapt the measure from Leonard et al (2018) to define prime farmland acreage as log of total reservation acreage where PI ≥9 (28). Schaetzl (2012) demonstrates that the PI on randomly selected agricultural sites for field crops in Michigan averaged 10.94 (SD ± 2.36) (76). A PI of 9 represents a lower standard for what comprises "prime" farmland. Tribes note that they often farm less than "prime" farmland due to lack of mechanization, traditional farming practices, and the need to produce food in spite of inefficiencies (13).

Agricultural Land Use on Reservations: We calculate agricultural land use acreage on reservations in 1974 using U.S. Contemporaneous Wall-to-Wall Anthropogenic Land Use Trends (NWALT) 60 m resolution geospatial data from 1974. Agricultural land use is defined as the sum of cropland acres (classification code 43) and hay/pasture acres (classification code 44) within reservation boundaries (77). This measure of reservation agriculture is indicative of a reservation's potential Winters entitlement: a record of crop production may reflect the reservation's need for a larger water entitlement to support irrigated agriculture.

Population growth rate: Decadal population growth rate is calculated for counties that intersect a reservation using US Census data from the decade prior to adjudication start. For reservations with unadjudicated water, 2000-2010 Census data are used to calculate the population decadal growth rate. County level census data prior to 1980 exclude reservation populations. Beginning in 1980, reservation population is subtracted from county-level population counts.

Adjudicated reservation area as a percentage of state area (res_state_pct): We calculate the ratio of adjudicated reservation area to total state area in two steps. First, we calculate for each $settlement_n$ the total land area of reservations within a $state_b$ on which Winters claims have been resolved prior to the year that $settlement_n$ was resolved. This includes the area of the reservations within the $settlement_n$. We then divide total adjudicated reservation area by the area of the $state_b$ and multiply by 100. Larger reservations may have larger claims to water. The variable reflects the amount of water within a state to satisfy tribal claims.

Environmental Characteristics:

Stream order: Stream order is an ordinal variable defined according to USGS as the highest stream order on a reservation. USGS assigns a numeric order to each link in a stream network, where a first order stream is the tributary closest to the headwaters in a watershed, a second order stream is the combination of two first order streams, a third-order stream is a combination of two order-two streams, and so forth.

Basin Precipitation spatial coefficient of variance: Calculated as the square root of spatial precipitation variance on basins overlying reservations within an adjudication agreement, divided by mean precipitation in those basins. The variable is calculated using 800m x 800m resolution PRISM 30-year normal precipitation from 1980-2010 that fell within the boundaries of basins that intersect reservations included in each adjudication agreement.

Basin area: Defined as the total area (square miles) of basins (HUC 6) that intersect the reservation included in each adjudication agreement.

Mean precipitation: Calculated as mean 30-year normal precipitation (mm) from 1980-2010, that fell within boundaries of the reservation during the months of April - September. The variable is calculated by interpolating monthly PRISM 30-year normal precipitation data with reservation boundaries in ArcGIS, and averaging precipitation over summer months.

Reservation to Basin Area Ratio: A proxy for a reservation's bargaining power within an adjudication, as a large land base within a fixed basin area signifies that a tribe has larger claims to water rights within that basin. The variable is calculated as the ratio of total reservation area to the sum of area of basins (HUC 6) included in the adjudication agreement.

Depletion Potential:

POD Density: The total number of off-reservation surface water points of diversion (POD) per square mile of basins (HUC6) intersecting each reservation. Basin area excludes reservation area. Surface water rights were almost fully allocated prior to the start of most Winters adjudications and are plausibly exogenous measures of Winters Rights adjudication determinants. Groundwater PODs are excluded as they are monitored inconsistently across states and many were established after Winters adjudications had started. Spatial data containing the POD location and water source were acquired from individual state water resource departments and state engineer's offices.

Economic Capacity:

Existing Irrigation infrastructure: Irrigation infrastructure is defined as a dummy variable where a reservation is assigned a value of 1 if a BIA irrigation project is present and a value of 0 if a BIA irrigation project is not present. BIA projects were constructed on 15 reservations in the early 1900s (78).

Fractionation: Level 1 fractionated acreage, as defined by Department of Interior (DOI), includes reservation acres with >1 unique ownership interest. Using data from the 2014 DOI Land Buy-Back Program status report, we calculate fractionated acreage as the percentage of total reservation area (79).

Access to credit: The number of lending institutions to which a reservation had access in 2018. Data identifying tribal lending institutions in the U.S. is available from the Minneapolis Federal Reserve. We collected supplementary data on the tribes served by each institution through information available on the institution's individual websites.

Per capita reservation income: From year 2000, available from the US Census.

Casino: A reservation is assigned a value of 1 if it operated a casino prior to adjudication start and is assigned a value of 0 if it did not operate a casino prior to adjudicating. Reservation with unadjudicated water rights are assigned a value according to their current casino operation. Data on casino operations was collected from 500nations.com, individual reservation websites, and worldcasinodirectory.com. Casinos were first authorized in 1988 under the Indian Gaming Regulatory Act.

BIA Self-Governance Program: An adjudication agreement is assigned a value of 1 if at least one reservation included in that agreement obtained BIA's Self-Governance status by 2019. To qualify, reservations must complete a planning phase, which includes legal and budgetary research, submit a request to participate, and demonstrate three years of financial stability and management capacity. Self-governance status enables reservations to control funding of, manage, and administer Indian Health Services programs for themselves. However, qualification criteria reflect tribes' abilities to develop submit plans that potentially entitle them to larger water entitlements. Data is publicly available from the BIA Indian Health Service.

Bargaining Parties:

Number of bargaining parties: For negotiated settlements, the number of bargaining parties is calculated as the total number of signatories to the settlement agreement. Bargaining parties in state court adjudications are calculated as the total number of parties recorded in individual case dockets.

Unique type of bargaining parties: Bargaining parties include signatories to settlement agreements and parties to state court decrees are categorized as a) reservations, b) state or federal government, c) irrigation districts, d) municipal water providers, e) individuals, and f) other. The variable is calculated as the number of bargaining party categories represented in the adjudication.

Urban land cover: A proxy for heterogeneous water demand, urban land cover area is defined as a percentage of off-reservation county area. The variable employs spatial data from the 1970-1980 Enhanced Historical Land Use and Land Cover Data Sets of the U.S. Geological Survey. Urban land cover is defined as "developed land" (classification codes 21-24) and is calculated for counties intersecting (but excluding) each reservation. While the dataset shows relatively rough urban landcover features in 200m x 200m polygons, we sacrifice resolution for an estimate of urban landcover that predates most adjudication start dates.

Democratic Congressional Majority: Calculated as the number of years when Democrats have a majority in the House and Senate, as a percentage of total years to resolve Winters claims.

Reservation to county-level PCI for the year 2000: Calculated as the ratio of reservation per capita income to per capita income in counties overlying reservations, using 2000 US Census data.

Dams: Calculated as the total number of dams within counties overlying each reservation in the decade prior to resolving Winters claims. Data is available from the National Inventory of Dams database.

A2. SUMMARY STATISTICS

Table A1-1: Summary Statistics, Mean and (standard deviation), by Adjudication Status

	Adjudicating	Not Adjudicating	Total
Number of Reservations	81	145	226
ln(Prime Acres)	9.420 (4.331)	5.728 (3.048)	7.051 (3.970)
Highest Stream Order (#)	5.319 (2.251)	2.75 (2.139)	3.668 (2.498)
Population Growth Rate (%)	30.332 (30.552)	12.809 (12.228)	19.329 (22.590)
POD Density (POD/mi^2)	0.001 (.0013)	0.001 (0.002)	.001 (.001)
Precipitation (mean)	24.805 (14.794)	30.094 (21.808)	28.198 (19.715)
Number of Lending Institutions (2018)	1.086 (1.200)	0.455 (0.764)	0.681 (.987)
Casino Prior to Adj. Start	.086 (.283)	0.503 (0.502)	.354 (0.479)
Reservation PCI 2000	11,160.99 (4175.923)	12,208.88 (5701.663)	11,651.01 (4957.478)
Fractionated Area (%)	18.491 (23.089)	24.642 (40.083)	22.016 (33.842)

Notes: Standard errors in parentheses. The sample contains 226 federally recognized reservations in AZ, CA, CO, ID, MY, NM, NV, OR, UT, WA, and WY. Navajo Nation counted as three separate reservations, as it has to adjudicate Winters claims separately in AZ, NM, and UT. Duck Valley is counted as two separate reservations, as it adjudicated Winters claims separately in ID and NV. Adjudicating reservations include those that have either resolved claims or have initiated the process of resolving claims. Not adjudicating reservations include those that have not initiated the adjudication process.

A3. Adjudication Determinant Tables

Table A3-1: Logistic Regression Results: Net Effects of Adjudication Determinants (Odds Ratios)

	All Reservations			2010 Reservation Population ≥100		
	(1)	(2)	(3)	(4)	(5)	(6)
ln(Prime Acres)	1.214**	3.123**	1.149	1.208**	2.992*	1.151
	(0.0998)	(1.747)	(0.0992)	(0.104)	(1.712)	(0.0993)
Highest Stream Order (#)	1.334***	1.811	1.186	1.288**	1.779	1.154
	(0.145)	(1.319)	(0.172)	(0.151)	(1.334)	(0.172)
Off-Res. Pop. Growth Rate	1.026***	1.128	1.023**	1.022***	1.125	1.023**
	(0.00800)	(0.0893)	(0.0112)	(0.00857)	(0.0905)	(0.0112)
POD Density	8.484e+108**	3.961e+144*	1.622e+140	1.462e+98*	3.89E+140	5.58E+129
	(1.073e+111)	(7.808e+146)	(3.218e+142)	(1.937e+100)	(7.77E+142)	(1.08E+132)
Precipitation	0.968**	0.953	0.949**	0.968**	0.955	0.951**
	(0.0136)	(0.0354)	(0.0201)	(0.0141)	(0.0369)	(0.0189)
BIA Region	1.416***	1.317	1.076	1.468***	1.384	1.038
	(0.177)	(0.650)	(0.171)	(0.197)	(0.857)	(0.169)
Lending Institutions (2018)			1.769*			1.739*
			(0.545)			(0.543)
Casino Prior to Adj. Start			0.0725***			0.0686***
			(0.0482)			(0.0454)
Reservation PCI 2000			1.000			1
			(5.85e-05)			(5.96E-05)
Fractionate Area (%)		1.016*			1.015*	
		(0.00839)			(0.00875)	
Constant	0.0125***	3.59e-08**	0.211	0.0183***	5.41e-08**	0.309
	(0.0102)	(2.56e-07)	(0.277)	(0.0174)	(4.05E-07)	(0.414)
Observations	216	82	138	154	69	135

Notes: Dependent variables in include prime reservation acreage, maximum Strahler Scale stream order on a reservation, population growth rate in counties overlying but excluding reservations in the decade prior to adjudication start, off-reservation points of diversion per mi^2 in basins overlying reservations, and a control for BIA region. Precipitation 1980-2010 normals within reservation boundaries is a measure of water scarcity. Columns 2 and 3 contain additional controls for economic capacity: fractionated land area as a percentage of reservation area, number of lending institutions available to a reservation in 2019, and the presence of a casino prior to adjudication start. Columns 4-6 are robustness checks based on reservation population, which is highly correlated (.8161) with reservation land area. Restricting our sample to reservations with populations ≥100 excludes most California rancherias, and smaller reservations that generally do not practice agriculture. Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A3-2: Linear Probability Model Regression Results: Net Effects of Adjudication Determinants

	All Reservations			2010 Reservation Population ≥100		
	(1)	(2)	(3)	(4)	(5)	(6)
ln(Prime Acres)	0.0260**	0.0686***	0.0190	0.0282*	0.0780***	0.02
	(0.0126)	(0.0191)	(0.0144)	(0.01)	(0.02)	(0.01)
Highest Stream Order (#)	0.0424**	0.0249	0.0201	0.0383*	0.01	0.02
	(0.0164)	(0.0208)	(0.0200)	(0.02)	(0.02)	(0.02)
Off-Res. Pop. Growth Rate	0.00555***	0.00589***	0.00366***	0.00490***	0.00628***	0.00343***
	(0.00115)	(0.00177)	(0.00124)	(0.00121)	(0.00181)	(0.00125)
POD Density (POD/mi2)	11.39	-9.911	27.37	9.87	(18.55)	25.50
	(20.57)	(24.52)	(20.23)	(24.23)	(25.43)	(20.28)
Precipitation (mm)	-0.00384***	-0.00373**	-0.00609***	-0.00481***	-0.00436**	-0.00609***
	(0.00140)	(0.00175)	(0.00156)	(0.0016)	(0.0019)	(0.0016)
BIA Region	0.348***	0.279***	0.171**	0.306***	0.258**	0.166**
	(0.0775)	(0.0975)	(0.0658)	(0.0790)	(0.1010)	(0.0653)
Number of Lending Institution (2018)			0.0735*			0.0717*
			(0.0395)			(0.04)
Casino Prior to Adj. Start			-0.415***			-0.430***
			(0.0823)			(0.08)
Reservation PCI 2000			-1.17e-06			-1.53E-06
			(8.35e-06)			(8.55E-06)
Fractionated Area (%)		0.000175			0.00035	
		(0.000964)			(0.00106)	
Constant	-0.00784	-0.339***	0.390**	0.08	-0.337**	0.426***
	(0.0665)	(0.0941)	(0.155)	(0.10)	(0.13)	(0.16)
Observations	216	82	138	154	69	135
R-squared	0.392	0.652	0.467	0.348	0.629	0.467

Notes: Dependent variables in include prime reservation acreage, maximum Strahler Scale stream order on a reservation, population growth rate in counties overlying but excluding reservations in the decade prior to adjudication start, off-reservation points of diversion per mi^2 in basins overlying reservations, and a control for BIA region. Columns 2 and 3 contain additional controls for economic capacity: fractionated land area as a percentage of reservation area, number of lending institutions available to a reservation in 2019, and the presence of a casino prior to adjudication start. Columns 4-6 are robustness checks, based on reservation population, which is highly correlated (.8161) with reservation land area. Restricting our sample to reservations with populations ≥100 excludes most California rancherias, and smaller reservations that generally do not practice agriculture. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

A4. Duration Analysis Tables

Table A4-1: Cox Proportional Hazard Regression Results

	(1) Adj Duration	(2) Adj Duration	(3) Adj Duration	(4) Adj Duration
Bargaining Parties	0.00525**	0.00839**	0.00618**	0.00940**
	(0.00247)	(0.00389)	(0.00257)	(0.00385)
Unique Party Types	0.0367	-0.00944	-0.0190	-0.0639
	(0.125)	(0.135)	(0.131)	(0.143)
Democratic Congress	0.0142*	0.0252***	0.0138	0.0262***
	(0.00861)	(0.00902)	(0.00867)	(0.00907)
Casino Prior to Adj. Start		-0.270	-0.716	-0.621
		(0.766)	(0.794)	(0.818)
Reservation PCI 2000		3.35e-05		3.57e-05
		(5.36e-05)		(5.33e-05)
Number of Lending Institutions (2018)			-0.188	-0.186
			(0.149)	(0.161)
Observations	44	41	44	41

Notes: Dependent variables include the number of bargaining parties upon resolving Winters claims, years of Democratic majority in the House and Senate as a percentage of adjudication years; unique bargaining party types as a measure of heterogeneity across water users. Columns 2-4 include variables for whether a reservation operated a casino prior to adjudication start, number of lending institutions, and reservation per capita income in 2000 as measures of reservation economic capacity. The hazard function represents the probability that an adjudication ends after having lasted t years. The CPH function is:

$$\lambda(t|X) = \lambda_0(t)e^{(\beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p)}$$

$\lambda(t|X)$ represents the proportional hazard as a function of the number of years to complete adjudication conditional on covariates representing determinants of contracting costs. $X = (x_1, x_2, \dots, x_p)$ is a vector of covariates and λ_0 is the hazard function. The ß coefficients describe the effect of covariates on the hazard rate once a reservation has initiated adjudication—a negative sign on a ß indicates a lower probability of adjudication in a given time period and thus a longer adjudication process. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A4-2: Alternative Specifications Cox Proportional Hazard Regression Results

	(1)	(2)	(3)	(4)
	Adj Duration	Adj Duration	Adj Duration	Adj Duration
Bargaining Parties	-0.00563**	-0.00863**	-0.00725***	-0.0102**
	(0.00249)	(0.00395)	(0.00264)	(0.00411)
Democratic Congress	0.0119	0.0237***	0.00824	0.0223**
	(0.00892)	(0.00913)	(0.00949)	(0.00956)
Urban Land Heterogeneity	0.000156	0.000138	0.000249*	0.000211
	(0.000118)	(0.000136)	(0.000133)	(0.000143)
Casino Prior to Adj. Start		0.0155	-0.615	-0.391
		(0.835)	(0.836)	(0.867)
Reservation PCI 2000		2.78e-05		3.00e-05
		(5.32e-05)		(5.19e-05)
Number of Lending Institutions (2018)			-0.352**	-0.285*
			(0.163)	(0.169)
Observations	44	41	44	41

Notes: This model includes urban land cover in 1980 in counties overlying reservations as a metric of water use heterogeneity. Urban Land Heterogeneity is calculated as (urban land cover as a percentage of county land cover)*(1-urban land cover as a percentage of county land cover). Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A4-3: Cox Proportional Hazard Regression Results

	(1)	(2)	(3)	(4)
	Adj. Duration	Adj. Duration	Adj. Duration	Adj. Duration
Bargaining Parties	-0.00578**	-0.00897**	-0.00685**	-0.0103**
	(0.00260)	(0.00437)	(0.00271)	(0.00462)
Democratic Congress	0.0139*	0.0248***	0.0136	0.0252***
	(0.00839)	(0.00875)	(0.00853)	(0.00894)
Basin Precipitation Spatial COV	1.902*	2.215*	2.361**	2.566**
	(1.102)	(1.306)	(1.170)	(1.286)
Casino Prior to Adj. Start		0.255	-0.332	-0.115
		(0.835)	(0.817)	(0.856)
Reservation PCI 2000		1.34e-05		2.13e-05
		(5.44e-05)		(5.29e-05)
Number of Lending Institutions (2018)			-0.258*	-0.238
			(0.153)	(0.164)
Observations	44	41	44	41

Notes: This model includes basin precipitation spatial coefficient of variation – calculated as the square rood of the basin precipitation variance for reservations in each adjudication agreement, over mean basin precipitation – as a measure of resource heterogeneity. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A4-4: Alternative Specifications Cox Proportional Hazard Regression Results

	(1) Adj. Duration	(2) Adj. Duration	(3) Adj. Duration	(4) Adj. Duration
Bargaining Parties	-0.00594**	-0.00905**	-0.00740***	-0.0106**
	(0.00265)	(0.00445)	(0.00270)	(0.00433)
Unique Bargaining Party Type	0.0591	0.0237	-0.00761	-0.0400
	(0.127)	(0.138)	(0.129)	(0.140)
Democratic Congress	0.0118	0.0239***	0.00964	0.0239**
	(0.00895)	(0.00918)	(0.00938)	(0.00953)
Urban Land Heterogeneity	0.000110	8.21e-05	0.000200	0.000145
	(0.000128)	(0.000146)	(0.000141)	(0.000149)
Basin Precipitation Spatial COV	1.365	1.910	1.585	2.027
	(1.265)	(1.415)	(1.329)	(1.406)
Casino Prior to Adj. Start		0.363	-0.350	-0.0954
		(0.875)	(0.873)	(0.907)
Reservation PCI 2000		1.38e-05		2.16e-05
		(5.42e-05)		(5.23e-05)
Lending Institutions			-0.361**	-0.311*
			(0.170)	(0.177)
Observations	44	41	44	41

Notes: This model includes three measures of heterogeneity: number of unique bargaining party types, urban land heterogeneity, and basin precipitation spatial coefficient of variation. Columns 2-4 include variables for whether a reservation operated a casino prior to adjudication start, number of lending institutions, and reservation per capita income in 2000 as measures of reservation economic capacity. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

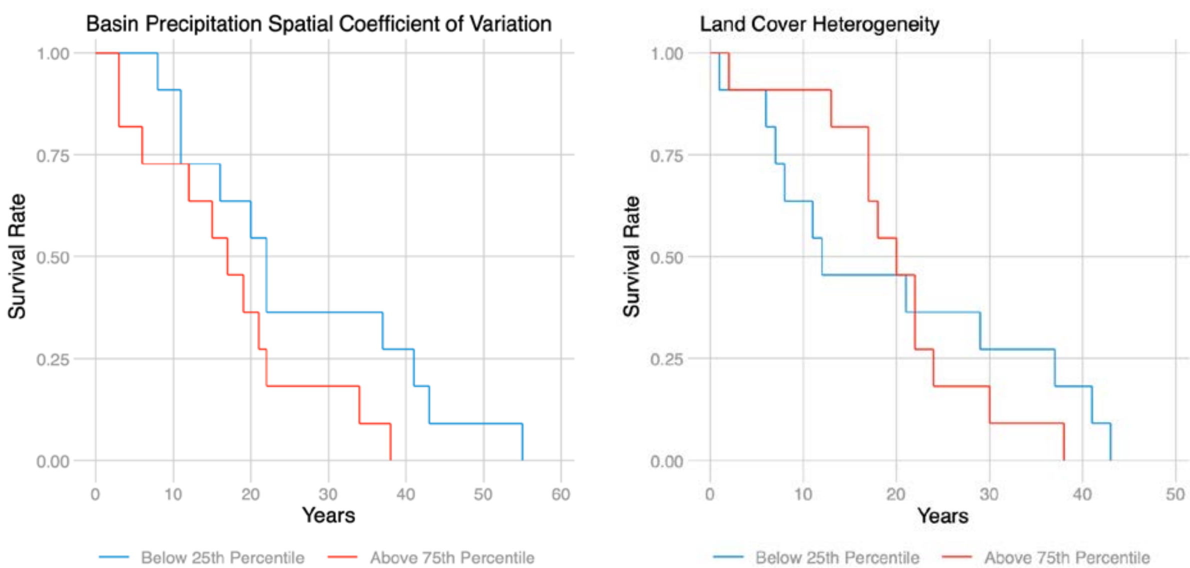

Figure A4-1: *Left - Kaplan-Meyer nonparametric estimate of the survival function for the upper and lower quartile of reservation precipitation spatial coefficient of variation. Right – Kaplan Meyer nonparametric estimate of the survival function for the upper and lower quartile of land cover heterogeneity*

A5. Adjudication Outcomes

Table A5-1: MLR Estimate of Federal Funding (2010 $ adj.)

	(1) Federal Funding	(2) Federal Funding	(3) Federal Funding	(4) Federal Funding	(5) Federal Funding	(6) Federal Funding
Resolution year	5.939e+06*	7.288e+06**	8.689e+06**	1.027e+07**	3.661e+06	5.003e+06*
	(3.064e+06)	(3.189e+06)	(4.188e+06)	(4.103e+06)	(2.798e+06)	(2.684e+06)
Democratic Congress in Resolution Year	8.007e+07	6.866e+07	1.014e+08**	9.045e+07*	9.898e+07**	8.778e+07*
	(4.879e+07)	(5.106e+07)	(4.238e+07)	(4.536e+07)	(4.586e+07)	(4.708e+07)
Off-Res. County Pop. Growth Rate	2.876e+06*	3.191e+06***	3.827e+06*	4.180e+06**	3.868e+06**	4.061e+06**
	(1.486e+06)	(1.112e+06)	(1.972e+06)	(1.515e+06)	(1.679e+06)	(1.567e+06)
Casino Prior to Adj. Start	-5.562e+07	-7.301e+07	-1.320e+08	-1.563e+08	-1.050e+08	-1.147e+08
	(6.221e+07)	(7.017e+07)	(9.322e+07)	(9.225e+07)	(9.457e+07)	(9.217e+07)
ln(Prime Reservation Acres)	2.137e+07**		2.328e+07**		1.727e+07**	
	(9.346e+06)		(1.023e+07)		(7.479e+06)	
Adjudicated Res: State Area (%)	1.102e+07	1.423e+07**	4.542e+06	7.686e+06	2.077e+07*	2.254e+07*
	(7.994e+06)	(6.830e+06)	(8.174e+06)	(5.620e+06)	(1.191e+07)	(1.155e+07)
ln(1974 Reservation Farmed Acres)		2.472e+07***		2.630e+07***		2.072e+07***
		(7.879e+06)		(8.167e+06)		(5.027e+06)
Self-Governance			-1.071e+08	-1.136e+08*		
			(7.165e+07)	(6.099e+07)		
BIA					-5.801e+07	-5.286e+07
					(4.773e+07)	(4.757e+07)
Constant	-1.212e+10*	-1.479e+10**	-1.763e+10**	-2.074e+10**	-7.317e+09	-1.000e+10*
	(6.194e+09)	(6.409e+09)	(8.449e+09)	(8.240e+09)	(5.662e+09)	(5.414e+09)
Observations	36	36	36	36	36	36
R-squared	0.279	0.367	0.312	0.404	0.415	0.478

Notes: The model includes off-reservation county population growth rate in the decade prior to resolving claims as a measure of growing competing demand for water, and therefore growing value of water. A settlement is assigned a value of 1 if Democrats held a majority in congress during the resolution year, when federal funding and water allocations were ratified. The ratio of adjudicated reservation area to state area are measures of appropriative water rights available within a state to satisfy tribal claims. Prime acreage and farmed reservation area in 1974 represent alternative measures for quantifying tribal claims. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A5-2: MLR Estimate of AFY Entitlement

	(1)	(2)	(3)	(4)	(5)	(6)
	AFY	AFY	AFY	AFY	AFY	AFY
Resolution year	-500.7	2,327	4,451	7,847	-2,312	888.6
	(6,784)	(5,551)	(7,196)	(5,306)	(6,353)	(5,257)
Democratic Congress in Resolution Year	26,145	3,695	64,546	44,078	41,177	15,732
	(119,553)	(96,361)	(120,717)	(94,247)	(120,231)	(97,449)
Off-Res. County Pop. Growth Rate	-1,388	-561.8	324.0	1,270	-599.1	-14.15
	(2,333)	(1,934)	(2,742)	(2,106)	(2,241)	(2,046)
Casino Prior to Adj. Start	-33,586	-63,052	-171,099	-217,395*	-72,850	-89,313
	(104,435)	(110,577)	(131,094)	(109,941)	(101,881)	(106,050)
ln(Prime Reservation Acres)	39,793***		43,241***		36,534**	
	(13,612)		(14,378)		(13,832)	
Adjudicated Res: State Area (%)	2,060	7,963	-9,597	-4,166	9,810	13,197
	(13,075)	(10,341)	(14,778)	(9,632)	(12,574)	(10,794)
ln(1974 Reservation Farmed Acres)		49,705***		52,631***		47,183***
		(12,440)		(12,052)		(12,623)
Self-Governance			-192,858*	-210,564*		
			(105,957)	(118,524)		
BIA					-46,122	-33,283
					(30,933)	(34,386)
Constant	786,765	-4.839e+06	-9.118e+06	-1.586e+07	4.608e+06	-1.824e+06
	(1.364e+07)	(1.114e+07)	(1.448e+07)	(1.067e+07)	(1.279e+07)	(1.058e+07)
Observations	36	36	36	36	36	36
R-squared	0.258	0.437	0.304	0.492	0.295	0.456

Notes: The model includes off-reservation county population growth rate in the decade prior to resolving claims as a measure of growing competing demand for water, and therefore growing value of water. A settlement is assigned a value of 1 if Democrats held a majority in congress during the resolution year, when federal funding and water allocations were ratified. Basin precipitation and the ratio of adjudicated reservation area to state area are measures of water available to fulfill tribal claims. Prime acreage and farmed reservation area in 1974 represent alternative measures for quantifying tribal claims. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A5-3: MLR Estimates for Predicted Settlement Outcomes

	ln(AFY)
Off-Res. County Population Growth Rate in Decade Prior to Resolution	0.00749
	(0.00933)
ln(Reservation Population) in Decade Prior to Resolution	0.557
	(0.366)
ln(Reservation Prime Acres)	-0.0713
	(0.164)
Basin Precipitation (mm)	-0.000499
	(0.0238)
ln(Reservation Area)	0.718**
	(0.292)
Adjudicated Res: State Area (%)	-0.292**
	(0.131)
Casino Prior to Adjudication Start (dummy)	0.477
	(0.967)
Self-Governance (dummy)	0.386
	(0.461)
BIA Region	0.179
	(0.218)
	3.100
Constant	(2.668)
	0.00749
Observations	35
R-squared	0.661

Notes: Regression for prediction of tribal water right claims. While there are 36 total completed negotiated settlements, our predictive analysis excludes the Timbi-Sha Shoshone reservation, which was established and received water rights in the year 2000. As such, there are no reservation-level data prior to the resolution of Winters claims. Variables were chosen for their ability to predict future outcomes and are the regression is jointly significant (p-value=0.0004). Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A5-4: Upper and lower bounds on predicted water right allocations for completed and ongoing adjudications and actual settlement amounts, where settled. Note: Pre-period population data not available for the Timbi-Sha Shoshone Reservation. The 95% confidence interval is related to the point estimate of the model prediction, not an assessment of the accuracy of the model in predicting future adjudications.

Adjudication Agreements	**Entitlement (AF/year)**	**Prediction (95% CI)** *Lower Bound*	*Upper Bound*
Timbi-Sha Shoshone	507	-	-
Lummi	685	3,327	9,489
Hualapai	694	10,498	22,493
Yavapai-Prescott	1,550	940	2,426
Las Vegas	2,000	3,218	6,502
Paiute (UT)	4,000	1,813	3,499
Fallbrook	4,994	4,930	12,570
Aamodt	6,467	20,023	33,939
Soboba	9,000	11,149	28,425
Fallon Paiute-	10,588	11,718	27,878
Zuni	10,600	38,366	56,673
Taos	14,058	19,738	37,473
San Luis Rey	16,000	58,687	135,722
Rocky Boy's	20,000	48,263	75,992
Duck Valley (ID)	32,062	51,146	107,998
Fort McDowell	36,350	5,959	9,076
Jicarilla	45,646	263,512	399,637
Nez Perce	50,000	159,300	248,159
San Carlos	77,435	200,198	330,436
Tohono O'odham	79,200	556,462	877,005
Maricopa	85,000	56,185	162,858
Northern Cheyenne	91,330	174,753	258,101
Fort Apache	99,000	61,807	104,792
Duck Valley (NV)	114,082	107,441	192,533
Salt River	122,400	47,010	91,476
Ute	225,488	557,225	855,970
Warm Springs	325,786	210,803	413,080
Fort Belknap	477,408	129,023	205,717
Uintah	481,035	378,843	617,026
Pyramid Lake	520,000	182,398	282,220
Navajo (NM)	633,532	398,000	897,131
Gila	653,500	53,507	82,597
Fort Hall	711,862	149,868	248,905
Blackfeet	750,000	73,435	104,463
Crow	847,000	144,373	209,488
Fort Peck	1,050,472	289,464	416,639
Total	**7,609,731**	**4,483,381**	**7,568,388**

Ongoing Adjudications	**Prediction (95% CI)** *Lower Bound*	*Upper Bound*
Tonto Apache	39	212
Yavapai-Apache	133	619
Bridgeport	324	1,399
Ramona	401	2,987
Benton Paiute	808	2,993
Yerington	941	2,312
Lone Pine	1,190	4,177
Havasupai	1,969	4,849
Big Pine	2,011	7,270
Santa Ana	4,819	8,146
Bishop	4,866	16,922
Zia	7,231	12,875
Cahuilla	10,291	27,892
Jemez	14,124	25,673
Hopi	18,628	38,960
Acoma	20,540	28,792
Navajo (AZ)	21,880	809,011
Navajo (UT)	22,461	83,670
Tule River	24,926	60,070
Laguna	31,126	41,942
Walker River	79,464	125,546
Flathead	108,338	268,887
Coeur d'Alene	125,250	469,559
Umatilla	165,260	872,767
Agua Caliente	342,783	1,821,713
Total	**1,009,803**	**4,739,242**

Notes: The estimated regression coefficients from table A5-3, specification (1) are used to predict all reservation adjudications. Because our regression has a logged dependent variable but we would like to construct confidence intervals for levels, we must transform back. The expected value of the transformed lognormal distribution, from Zhou and Gao (1997), is: $\hat{p} = e^{\hat{\mu}+\frac{1}{2}\hat{\sigma}_n^2}$. We construct a confidence interval, from Olsson (2005), of the exponent of:

$$\left(\hat{\mu} + \frac{1}{2}\hat{\sigma}_n^2\right) \pm t\sqrt{\frac{\hat{\sigma}_n^2}{n} + \frac{\hat{\sigma}_n^4}{2(n-1)}}$$

Where t is the Student's t-distribution test statistic with degrees of freedom n. We use n equal to the number of observations in each regression.