Environmental Research Letters

ACCEPTED MANUSCRIPT • OPEN ACCESS

The economics of indigenous water claim settlements in the American West

To cite this article before publication: Leslie Sanchez *et al* 2020 *Environ. Res. Lett.* in press https://doi.org/10.1088/1748-9326/ab94ea

The Economics of Indigenous Water Claim Settlements in the American West

Leslie Sanchez, Eric C. Edwards, and Bryan Leonard[1]

ABSTRACT

The American West confronts the challenge of fulfilling indigenous claims to water within the context of increasingly scarce and variable water supplies. 170 of 226 American Indian reservations have unresolved water claims that potentially exceed the region's hydrological capacity, generating uncertainty for tribes and off-reservation water users. To help resolve key uncertainties about dispute origins and outcomes, we construct a complete and novel dataset on Indian water settlements and reservation characteristics which we then analyze using a bargaining framework from economics. We find that rapid off-reservation population growth, water scarcity, and large anticipated water entitlements catalyze disputes. When more users are involved in the negotiations, transaction costs delay settlement, increasing water insecurity. We use our findings to predict allocations for 25 ongoing water right negotiations. These estimates help bound the uncertainty facing water managers throughout the American West.

[1] Tufts University, North Carolina State University, and Arizona State University respectively. Corresponding author: Leslie Sanchez (leslie.sanchez@tufts.edu). Funding for this project was provided by USDA AFRI (2015-69007-23190; Hatch project 1017720; and Multistate project 1020662) and from the Babbitt Center for Land and Water Policy.

The data that support the findings of this study are available upon request from the authors.

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). Sustainable water management in the West requires changes in the pattern and overall level of water use to reconcile the historic concentration of water use in irrigated agriculture and growing urban demands and with supplies that are becoming more variable at scales ranging from small streams to the Colorado River itself (2,3). The recognition of Native Americans' long-neglected—and often substantial—rights to water looms large in the future of water in the West because satisfying these claims is costly and could entail major changes in distribution of water rights (4).

The U.S. Supreme Court ruled in *Winters vs. United States* that the treaties signed with tribes in western states entitle them to federally reserved water rights that supersede other water uses developed subsequent to the formation of reservations in the late 19th century (5). Since the original ruling in 1908, only 56 of 226 federally recognized reservations in the western US have settled Winters claims. The most commonly cited figure for 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 (6). This is three times the annual usage for 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 (7).

Despite the potential importance of tribal water claims, the process that determines the ultimate outcome is not well-understood. 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 (4). 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 water rights appear to be stronger economically and agriculturally, but do not explore a complete set of western reservations over time (8).

We fill this critical knowledge gap by combining historical documents and settlement agreement texts for all settled Winters claims with historical geospatial data on land and water use, government reports, and surveys of reservation-level socioeconomic characteristics for the full set of western reservations. We then adopt the economic framework developed Ayres, Edwards, and Libecap (2018) for the adjudication of groundwater rights (9) to our setting and study both the determinants and outcomes of Winters claims. Hence, we contribute to the literature on water rights adjudication by extending Ayres et al. (2018) to a new setting and also provide important new insights into ongoing tribal water rights settlements. We then use these insights to predict the total volume of outstanding tribal water allocations.

Uncertainty about when and where tribes will assert Winters claims, the costs of resolving those claims, and potential changes in the distribution of water rights constrains economic development, inhibits investments and long-term water supply and demand planning, and impedes drought adaptation strategies and regional water-sharing agreements – all of which rely on well-defined and secure water rights. Thus, while understanding the outcomes of adjudications themselves is important, so too is understanding adjudication catalysts, the causes of delay and discord, and how delays can be overcome.

In the first stage of our analysis, we test for factors that increase a reservation's likelihood of initiating adjudication (10), and find that tribes are more likely to assert their claim in response to rapid population growth off-reservation, water scarcity, and large anticipated water entitlements. We then examine adjudication, or transaction, costs which may impede settlements (9), and find that adjudications involving more bargaining parties take significantly longer to resolve—the mean adjudication involves 33 parties and lasts 21 years. Finally, we use these insights to estimate the expected volume of water entitlements allocated to each tribe in ongoing settlement agreements. Our predictions of total water entitlements range between 1.2-1.6 million AFY, which is considerably less than the Western States Water Council's 1983 estimates of ~16 million AFY for these 25 reservations (6).

HISTORICAL BACKGROUND

Surface waters in western states are 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 were appropriated without regard for the needs of American Indian reservations. Although the federal government had treaty obligations to provide water for tribes, the allocation of individual water rights is the responsibility of states, which favored the interests of white settlers over pre-existing uses by indigenous peoples (11).

By the mid-1900's, most streams were fully allocated and dammed, diverted, and appropriated for irrigated agriculture, as well as energy, mining, and urban development, by non-indigenous water users (12). As off-reservation water use exceeded the limits of natural system sustainability, tribal water availability became highly constrained and uncertain. Reservation agriculture in the Southwest and tribal fisheries in the Pacific Northwest declined when off-reservation irrigators depleted reservation streamflow and springs (13–16). The National Water Commission acknowledged in 1973 that "[i]n the history of the United States Government's treatment of Indian tribes, its failure to protect Indian water rights for use on the Reservations it set aside for them is one of the sorrier chapters" (17).

In 1908, the US Supreme Court (*Winters v. United States*) ruled that tribes have water rights "sufficient to fulfill the need of the reservation as a homeland" (5). Crucially, these "Winters Rights" are federally reserved water rights with priority based on the date a reservation was established. In many basins, this meant that tribes had implicit but unquantified rights with greater seniority than most existing water users that established water rights *after* reservations were formed. However, because the ruling did not explicitly grant tribes appropriative rights or establish metrics to determine what quantity of Winters Rights tribes should receive, conflict persists between existing water users and contemporary Winters Right claims (17).

Winters Rights are adjudicated either via court decree achieved through litigation or 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 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. Figure 1 shows the location of reservations in western states and their adjudication status.

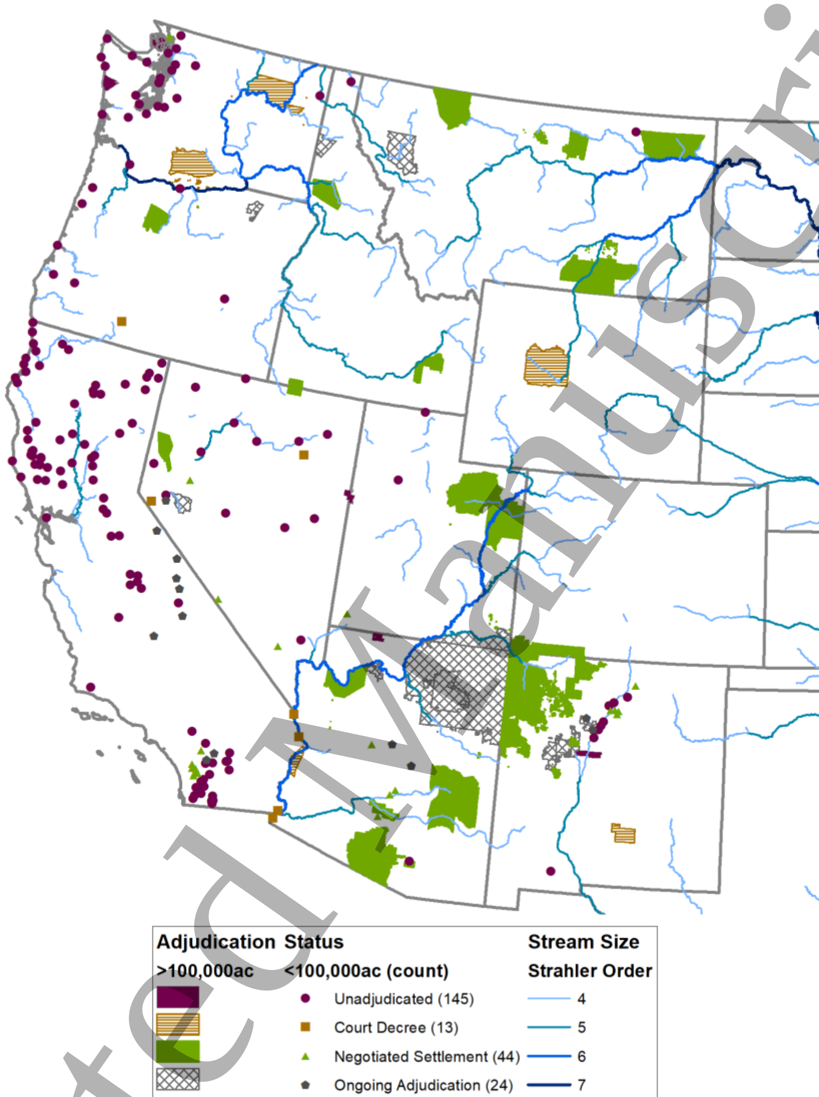

Figure 1. ***Adjudication status of western reservations.*** *Reservations under 100,000 acres are represented as symbols while those over 100,000 acres are represented according to reservation acreage. Navajo Nation and Duck Valley Reservation span multiple states, and their adjudication status is provided separately for each state.*

METHODS

Economic Framework

Ayres, Edwards, and Libecap (2018) develop an 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 (9). 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, if sufficient water is available (18). The marginal value of surface water increases where precipitation and streamflow are scarce (19). 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 (20). 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 (21). Off-reservation right holders participate in negotiations to resolve uncertainty about how Winters Rights will be accommodated (i.e. from which appropriators), or to avoid being litigants to proceedings in state courts.

Agreement may prove elusive even when the net gains from settlement are positive for the basin as a whole (22). Some users who do well under the status quo may oppose agreement, and the costs to bring them on board may be high. Perramond (2018) finds evidence that adjudications in New Mexico required such high levels of spending to facilitate agreement that the costs may have exceeded the aggregate value of the water in the agreement (23). Increases in the number and heterogeneity of bargaining parties tend to increase the transaction costs of negotiation and make agreement less likely, although this is not always the case (10,24). Heterogeneity in physical water availability, such as across water users in a basin, influences information costs and bargaining positions of adjudication parties (25).

Conflicting bargaining positions arise from different perceptions of fairness and from information asymmetries (22). If the legal outcome of cases is not clear because of limited precedent, opportunities for negotiation 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 (26). 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 (27). Federal funding in negotiated settlements can defray high contracting costs and facilitate agreement. For instance, many settlements include compensation for irrigation districts that forfeit water to satisfy newly defined Winters Rights (28).

Our empirical study focuses on 226 federally recognized reservations in the 11 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, leaving 145 that have not yet started the process. Figure 2 depicts adjudication timelines for these 81 reservations. Of these, 56 reservations have resolved their Winters claims—44 through negotiated settlements and 12 through 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.

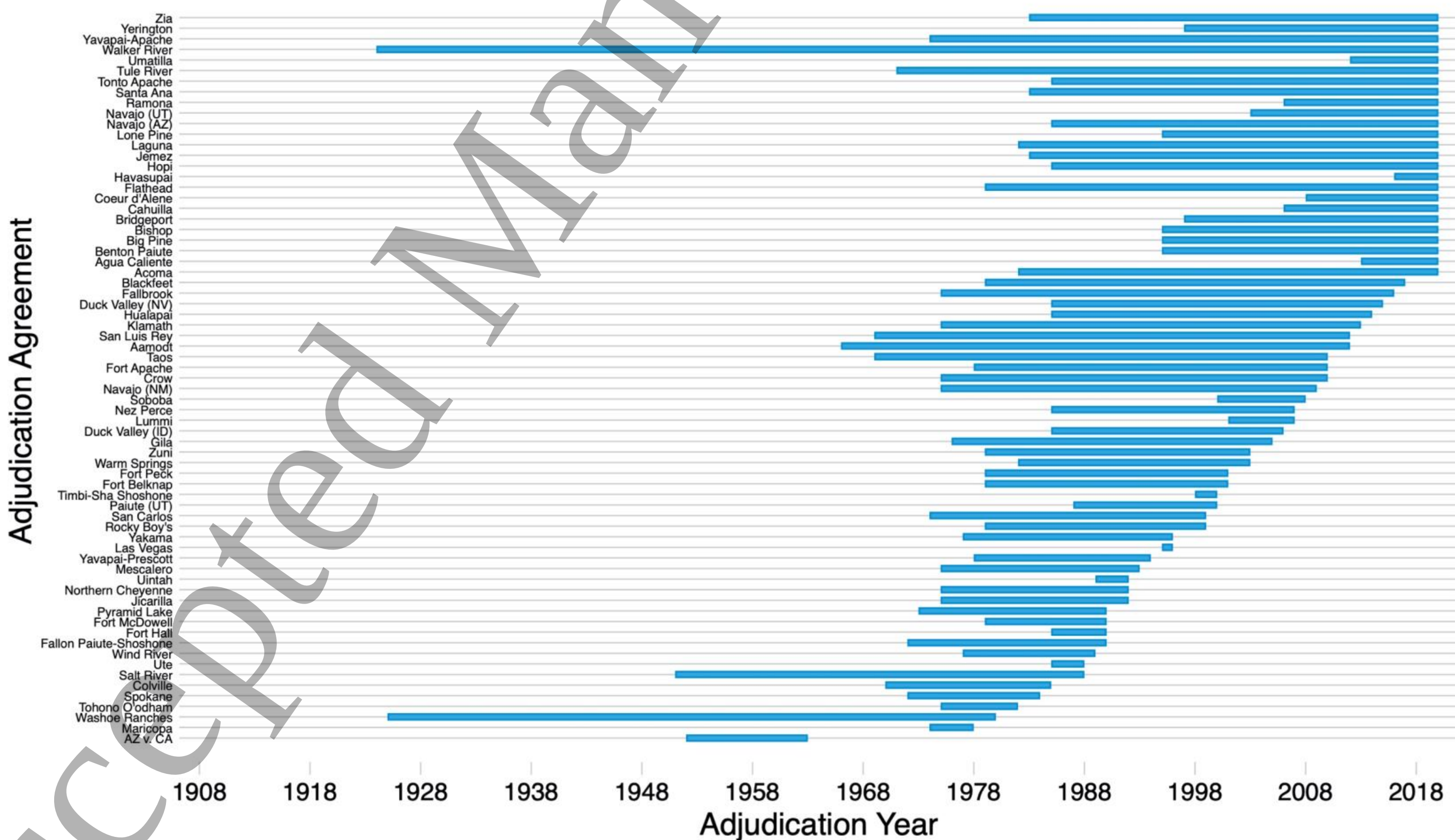

Figure 2. Timeline of Winters Rights adjudication negotiations and resolutions. *Blue bars begin at date when adjudication effort begins and end when ratified. Bars extending to 2019 are ongoing.*

Likelihood of Adjudication

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 using a logistic regression model. We model the unobserved benefits of an adjudication for reservation i, adj_i^*, as a function of $\boldsymbol{B_i}$, a vector of adjudication benefit factors for each reservation:

$$adj_i^* = \boldsymbol{B_i}\beta + e_i \qquad (1)$$

Where e_i is the standard econometric error term. We observe the outcome of whether a tribe has initiated the adjudication process adj_i, where $adj_i = \{0,1\}$ represents {non-adjudicating, adjudicating}. We assume that $adj_i = 1$ when the unobserved benefits of adjudication exceed the cost, $adj_i^* > \kappa$, and estimate our model using a logistic regression. The magnitude of slope estimates, $\hat{\beta}$, indicate the extent to which an independent variable increases or decreases the likelihood of entering the adjudication process.

Independent variables, described in Table 1, are either time-invariant or constructed to measure conditions prior to the start of adjudication. The approach is potentially susceptible to omitted variable bias. We include several robustness checks controlling for common metrics that affect reservation outcomes like access to credit, casino operation, and reservation per capita income, to reduce these concerns. Prime acreage, adapted from Leonard et al (2020), is an exogenous measure of the area of land that irrigation water could be put to agricultural use on-reservation (29). It is indicative of larger water claims, and therefore a larger opportunity cost of forgoing adjudication. Stream order measures water availability. To the extent that adjudication costs are fixed, larger volumes of water found in larger streams will result in lower adjudication costs per unit of (30). Off-reservation population growth reflects water value over time; point-of-diversion density and precipitation are measures of water scarcity. Summary statistics are presented in Table A1-1.

Table 1: Independent Variables for Logistic Probability Model

Variable	Definition	Source
Prime Acreage	Reservation logged acreage with a productivity index ≥9	Schaetzl, 2012
Stream Order	Highest stream order within reservation boundaries	USGS
Off-Reservation Pop. Growth Rate	Population growth rate (%) of counties overlying reservation in the decade prior to adjudication start. The measure excludes reservation populations.	US Census
POD Density	Number of off-reservation surface water points of diversion per square mile of HUC6 basins intersecting the reservation.	State Water Resource Depts
Precipitation	1980-2010 mean 30-year normal precipitation (mm) that fell within reservation boundaries during the months of Apr.-Sept.	PRISM
BIA Region	Categorical variable representing BIA region in which reservation is located	BIA
Credit (2018)	Number of tribal lending institutions to which a reservation had access in 2018.	Minneapolis Federal Reserve
Casino Prior to Adjudication Start	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. Reservations with unadjudicated water rights are assigned a value according to their current casino operation.	500nations.com Worldcasinodirectory.com
Reservation PCI	Per capita reservation income in year 2000	US Census

Adjudication Duration

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. Duration is measured as the number of years between initiating and finalizing the adjudication. We construct a second dataset for 44 adjudication agreements that have resolved Winters claims for 56 reservations. We use a Cox Proportional Hazard Model (CPH) to test the effect of covariates on the time to resolve Winters claims. The hazard function represents the probability that an adjudication ends after having lasted t years:

$$\lambda(t|\boldsymbol{C}) = \lambda_0(t)e^{\boldsymbol{C}_i\gamma} \quad (2)$$

Where $\lambda(t|\boldsymbol{C})$ represents the proportional hazard as a function of the number of years to complete adjudication conditional on covariates, $\boldsymbol{C_i}$, representing determinants of contracting costs, and λ_0 is the hazard function. The estimated coefficients, $\hat{\gamma}$, describe the effect of covariates on the hazard rate once a reservation has initiated adjudication (a negative sign indicates a lower probability of adjudication in a given time period and thus a longer adjudication process). Table 2 describes the independent variables used in this analysis, while summary statistics are presented in Table A1-2.

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 (UNM) Native American Water Rights Settlement Project. Primary data on litigated adjudications comes from State and District court filings and from the Indian Claims Commission Decisions housed at the Oklahoma State University Library. A large number of bargaining parties may complicate, and thus delay the resolution of Winters claims. Unique party types and spatial covariance of precipitation are measures of bargaining party and resource heterogeneity, which may increase time to resolve Winters claims. Democratic Congressional majority, from Congressional Research Service (CRS) data, measures the partisan priorities involved in resolving Winters claims.

Table 2: Independent Variables for CPH Duration Analysis

Variable	Definition	Source
Bargaining Parties	The total number of either a) signatories to the settlement agreement, or b) the total number of parties recorded in individual court case dockets.	UNM; US Courts
Unique Party Types	Bargaining parties are categorized as a) reservations, b) state or federal government, c) irrigation entities, d) municipal water providers, e) individuals, and f) other. The variable is calculated as the total number of party categories present in each adjudication.	UNM; US Courts
Basin Precipitation Spatial Covariance	Square root of spatial precipitation variance on basins overlying reservations within an adjudication, divided by mean precipitation in those basins.	PRISM
Democratic Congress	Number of years of Democratic majority in the House and Senate, as a percentage of total years to resolve claims.	CRS

Predicting Future Adjudications

Finally, we assess the distribution of water entitlements of 36 negotiated settlements to the 44 reservations included in those agreements to create a prediction of pending adjudications. The ultimate distribution of a tribal water entitlement as defined in each adjudication agreement is measured as the annual acre-foot per year (AFY) volume of non-consumptive water rights assigned under the agreement.

We identify settlement-level covariates that potentially affect the ultimate distribution of water entitlements. Prime acreage, reservation acreage, and farmed acreage (1974) reflect the volume of legal claims to water, as well as water demand. Although farmed acreage was not used in our test of likelihood of adjudication because 1974 data do not predate earlier court decreed adjudications, we use it here as a predictor. Farmed acreage is available from the U.S. conterminous wall-to-wall anthropogenic land use trends (NWALT) 1974-2012 dataset (31). The year when a settlement is finalized, stream order, off-reservation population growth rate prior to settlement, mean basin precipitation, and adjudicated reservation area within a state as a percentage of state area are measures of water scarcity. Controls include casino operation; reservation population prior to settlement, and BIA region.

We use the Akaike Information Criterion corrected for small sample size (AICc) to select a parsimonious model for predicting water entitlements of pending adjudications (32). First, we calculate the AIC score for potential model specifications:

$$AIC_i = 2K - 2\ln(\mathcal{L}) \quad (3)$$

Where AIC_i is a relative score assigned to each potential model, i, K is the number of parameters in the model, and $\mathcal{L}$ is the maximum value of the likelihood function of the model. We correct for small sample size using the $AICc$ formula:

$$AICc_i = AIC_i + \frac{2K^2 + 2K}{n - K - 1} \quad (4)$$

Where $AICc_i$ is the second order AIC_i score assigned to each potential statistical model and n is the number of observations.

We select the model with the lowest AICc score, and use a multilinear regression model to test the relationship between our predictors and AFY outcomes:

$$\ln(AFY_i) = \alpha + \boldsymbol{X_i}\eta + u_i \quad (5)$$

Our dependent variable, $\ln(AFY_i)$, is the logged AFY entitlement awarded in settlement, i, and X_i, is a vector of explanatory variables selected via AICc. The magnitude of the estimated coefficients, $\hat{\eta}$, indicate the extent to which independent variables are correlated with water entitlement outcomes. Using these model parameters, we predict water entitlements for 25 ongoing adjudications.

RESULTS

Water Scarcity Drives Adjudications

We first test the relationship between adjudication benefits and the probability the adjudication process is initiated. Because the coefficient estimates are difficult to interpret, we estimate equation 1 and report the odds ratios in Table 3. A larger odds ratio indicates that a variable makes adjudication more likely. The results indicate that the probability of pursuing adjudication increases when the value of water rises through increasing demand, constrained supply, and rising opportunity costs of forgoing adjudication. Off-reservation population growth rate in the decade prior to adjudication start is positively correlated with the probability of tribal adjudication. As populations grow, water demand increases, as do the expected benefits of legally secure water rights. Mean precipitation is negatively and significantly correlated with the probability of a reservation having initiated adjudication. Less precipitation is indicative of water scarcity, which increases the relative value of water.

All else equal, reservations with higher prime acreage are more likely than their counterparts to pursue adjudication. Stream order positively predicts adjudication in model specifications that exclude controls for income and access to credit. Both results are statistically significant at the 10% or higher level in most, but not all, the specifications. Greater prime acreage and larger streams are key variables determining the volume of water per dollar of fixed adjudication costs and are indicative of larger anticipated adjudication benefits relative to costs. Findings are generally consistent across the full sample of reservations and a restricted sample of reservations with a 2010 population of at least 100.

Table 3 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)	1.217**	1.188*	1.152	1.210**	1.178*	1.155*
	(0.0998)	(0.105)	(0.0996)	(0.104)	(0.107)	(0.0997)
Stream Order	1.334***	1.389***	1.185	1.285**	1.262*	1.152
	(0.145)	(0.166)	(0.172)	(0.151)	(0.173)	(0.172)
Off-Res. Pop. Growth Rate	1.026***	1.029***	1.024**	1.022***	1.023**	1.023**
	(0.00796)	(0.00938)	(0.0111)	(0.00853)	(0.0103)	(0.0111)
POD Density	1.402	1.575*	1.551	1.353	1.494	1.494
	(0.289)	(0.407)	(0.500)	(0.294)	(0.408)	(0.470)
Precipitation	0.970**	0.969**	0.952**	0.970**	0.967**	0.953**
	(0.0132)	(0.0137)	(0.0190)	(0.0137)	(0.0131)	(0.0179)
BIA Region	1.409***	1.098	1.073	1.461***	1.048	1.035
	(0.179)	(0.157)	(0.171)	(0.198)	(0.174)	(0.169)
Casino		0.102***	0.0742***		0.0829***	0.0699***
		(0.0483)	(0.0486)		(0.0439)	(0.0456)
Credit (2018)			1.734*			1.707*
			(0.524)			(0.524)
Reservation PCI 2000			1.000			1.000
			(5.78e-05)			(5.89e-05)
Observations	216	216	138	154	154	135

Notes: Columns 4-6 serve as robustness checks based on reservation population. Restricting our sample to reservations with populations ≥100 excludes most California rancherias, and smaller reservations that generally do not practice agriculture. Linear probability model results, presented in Table A2-1, serve as a robustness check and are consistent with logistic regression results. All model specifications include a constant. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Contracting Costs Lengthen Negotiations

We test the relationship between the duration of negotiations and predictors of high contracting costs. CPH results are shown in Table 4. 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. We test for the effect of heterogeneity in the types of bargaining parties but find ambiguous results. Spatial precipitation heterogeneity is, unexpectedly, weakly correlated with more expeditious resolution of claims.

Results also suggest that a higher percentage of years of Democratic congressional majority is significantly correlated with a more expedited adjudication process when controlling for economic characteristics of tribes. 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.

Table 4: Cox Proportional Hazard Regression Results

	(1) Duration	(2) Duration	(3) Duration	(4) Duration	(5) Duration	(6) Duration
Bargaining Parties	-0.00525**	-0.00839**	-0.00940***	-0.00578**	-0.00897***	-0.0103***
	(0.00255)	(0.00343)	(0.00361)	(0.00248)	(0.00340)	(0.00361)
Democratic Congress	0.0142	0.0252**	0.0262**	0.0139	0.0248**	0.0252***
	(0.0120)	(0.0110)	(0.0107)	(0.0106)	(0.00967)	(0.00912)
Unique Party Types	0.0367	-0.00944	-0.0639			
	(0.107)	(0.123)	(0.136)			
Basin Precipitation Spatial COV				1.902*	2.215	2.566*
				(1.105)	(1.383)	(1.433)
Casino		-0.270	-0.621		0.255	-0.115
		(0.802)	(0.854)		(0.831)	(0.843)
Reservation PCI 2000		3.35e-05	3.57e-05		1.34e-05	2.13e-05
		(8.00e-05)	(7.80e-05)		(7.99e-05)	(7.69e-05)
Credit (2018)			-0.186			-0.238**
			(0.130)			(0.119)
Observations	44	41	41	44	41	41

Notes: Results are displayed as coefficients. A negative sign on the coefficient implies a negative marginal effect on the hazard rate, which, all else equal, increases the expected duration of the adjudication process. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Determinants and Predictions of Water Entitlements

AICc results (Table A3-1 and Table A3-2) relating entitlement outcomes and control variables indicate that a model with the lowest AICc score ($AICc = 108.999$) includes logged farmed acreage (1974), mean basin precipitation, and logged reservation acreage. Using this model, we use a multilinear regression to analyze the outcomes of completed negotiated settlement agreements (Table 5).

Table 5: MLR Estimates of AFY Entitlements

	ln(AFY)
Logged reservation acreage	.4047***
	(.1263)
Mean basin precipitation	-.0419***
	(.0146)
Logged reservation farmed acreage (1974)	.4030***
	(.0891)
Observations	36
R-squared	0.7811

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

All else equal, water entitlement volumes are positively and significantly correlated with reservations' farmed acreage in 1974, and with total reservation acreage. Mean basin precipitation, indicative of water available to satisfy water claims, is negatively correlated with water entitlement levels within a settlement.

We extend these parameters to predict water entitlement outcomes to 25 reservations currently undergoing adjudication. Figure 3 shows the predicted outcomes of the 25, in red, along with actual negotiation outcomes relative to the amount the model predicts of the 36 reservations from table 5, in blue. Prediction results for 25 individual adjudicating reservations are shown in Table A3-3, where we provide the 95% confidence interval around the mean settlement prediction. Our prediction of total water entitlements range between 1.2-1.6 million AFY, which is considerably less than the Western States Water Council's 1983 estimates of ~16 million AFY for these 25 reservations (6). Prediction estimates should be interpreted with some caution because there is no established metric for quantifying tribal water allocations; the confidence intervals represent modeling uncertainty, not uncertainty of expected outcomes.

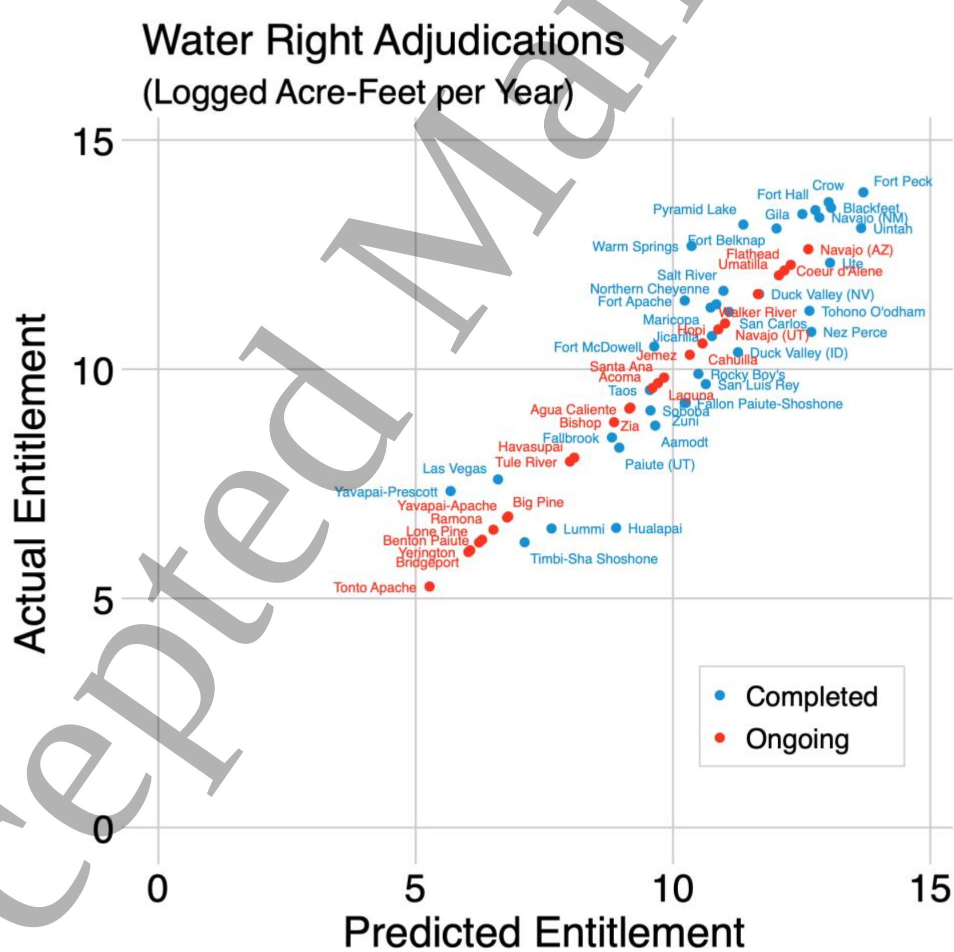

Figure 3: MLR Results. *Predicted versus estimated water right entitlement outcomes of Winters adjudications (blue) and predicted outcomes of ongoing adjudications (red).*

DISCUSSION

This article provides new insight into the physical and economic context in which legal disputes over tribal water rights are resolved. These outcomes are informative beyond the western United States. In Chile and Australia, for instance, 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 less than .01% of total water allocations (33). In arid northern Chile, the desiccation of indigenous water sources via legal groundwater right extractions has led to considerable legal uncertainty over the use and transfer of all water rights (34).

Our analysis of a new, comprehensive dataset of Winters outcomes shows 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 increases. Tribes are also more likely to pursue adjudication when the amount of settlement is expected to be sufficiently large to overcome the costs of negotiating. However, high contracting costs deter tribes from resolving legal claims. Ayres et al. (2018) also found bargaining costs hampered agreement, but the outcomes of tribal adjudications suggest a greater importance of the number of bargaining parties, rather than the heterogeneity of bargaining parties, in raising these costs.

Because many tribes face lengthy adjudication, reservation populations and ecosystems may continue to endure water shortages for years after an adjudication is initiated. Hence, transaction 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 (13,35). Meanwhile, off-reservation water users forego economic benefits of water right security, as disputes over water deter investments in agriculture and urban development and inhibit accurate water planning.

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. Once a tribe begins to pursue a negotiated settlement, the number of parties typically falls. Our work provides insight into reducing the length of the adjudication process: high numbers of users delay settlement, so opting to negotiate earlier in the adjudication process may reduce the overall duration—and costs—of resolving Winters claims.

Even as off-reservation agricultural water use is declining (36), the incentives embedded in Winters adjudication process 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 (37). Given that agriculture is an inherently water-intensive activity, tribes can improve their bargaining positions by asserting Winters claims based on the amount of farmed 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 (38).

This paper relies on several key assumptions. First, the statistical analysis is primarily based on statistical correlations and causal interpretations based solely on this work should be undertaken with caution. 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. Finally, the study focuses only on outcomes for federally recognized tribes legally able to claim Winters Rights, but this distinction does not fully capture all potential claims to water by indigenous groups (23).

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. We find that a key predictor of water allocations is farming capacity, how much agriculture the tribe undertook in 1974, which is fixed for each tribe. 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 by a factor of 10. 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 reduce the challenges faced by policymakers and water managers in reallocating water rights, it underscores the enduring negative impacts of reservation-era policies for tribes who now have limited prospects for securing substantial water rights.

Winters settlements, however, do provide benefits for tribes by creating secure property rights and resolving uncertainty. Moreover, they have generated opportunities to implement water marketing activities to address shared water shortages, potentially bringing stressed natural systems into more sustainable use (4). They have also moved water off-reservation via leases to users who have more capacity to place the water in high-value uses (39). In a recent example, the Gila River Indian Community will lease 200,000 acre feet to the Arizona Water Banking Authority in 2019 and 2020 as part of the Lower Colorado River Drought Contingency Plan (40). The leasing of adjudicated Winters Rights offers revenue for tribes and the potential for water managers to address ecological and urban water shortfalls, but has also been characterized as another pathway for tribally-owned resources to be consumed off-reservation (41). A key question for future research revolves around characterizing what happens to Winters Rights after agreement, and what the impact of settlements has been on tribal economic, social, and environmental outcomes.

REFERENCES

1. Dettinger M, Udall B, Georgakakos A. Western water and climate change. Ecol Appl. 2015;25(8):2069–93. https://doi.org/10.1890/15-0938.1

2. Gregory J, Stouffer RJ, Molina M, Chidthaisong A, Soloman S, Raga G, et al. Climate change 2007: the physical science basis. 2007.

3. Olmstead SM. The Economics of Managing Scarce Water Resources. Rev Environ Econ Policy. 2010 Jun 24;4(2):179–98. https://doi.org/10.1093/reep/req004

4. Womble P, Perrone D, Jasechko S, Nelson RL, Szeptycki LF, Anderson RT, et al. Indigenous communities, groundwater opportunities. Science. 2018 Aug 3;361(6401):453–5. https://doi.org/10.1126/science.aat6041

5. Winters v. United States. 1908.

6. Western States Water Council, Norman K. Johnson. Indian Water Rights in the West. 1983 Dec.

7. Bureau of Reclamation. Colorado River Basin Water Supply and Demand Study Final Study Reports Technical Report C - Water Demand Assessment. Department of Interior; 2012 Dec.

8. Deol S, Colby B. Tribal Economies: Water Settlements, Agriculture, and Gaming in the Western U.S. J Contemp Water Res Educ. 2018 Apr;163(1):45–63. https://doi.org/10.1111/j.1936-704X.2018.03269.x

9. Ayres AB, Edwards EC, Libecap GD. How transaction costs obstruct collective action: The case of California's groundwater. J Environ Econ Manag. 2018;91:46–65. https://doi.org/10.1016/j.jeem.2018.07.001

10. Libecap GD. Contracting for Property Rights. Cambridge University Press; 1993. 148 p.

11. Leonard B, Libecap GD. Collective action by contract: Prior appropriation and the development of irrigation in the western United States. J Law Econ. 2019;62(1). https://doi.org/10.1086/700934

12. Kendy E, Aylward B, Ziemer L, Richter B, Colby B, Grantham T, et al. Water Transactions for Streamflow Restoration, Water Supply Reliability, and Rural Economic Vitality in the Western United States. JAWRA J Am Water Resour Assoc. 2018;54(2):487–504. https://doi.org/10.1111/1752-1688.12619

13. Soboba Band of Mission Indians v. United States of America. 1976.

14. The Tohono O'odham Nation of Arizona Testimony of the Honorable Edward D. Manuel, Chairman. Sect. U.S. House of Representative House Natural Resources Committee Legislative Hearing on H.R. 1904, the Indian Water Rights Extension Act Apr 4, 2019.

15. Hillman B, Douglas EM, Terkla D. An analysis of the allocation of Yakima River water in terms of sustainability and economic efficiency. J Environ Manage. 2012 Jul;103:102–12. https://doi.org/10.1016/j.jenvman.2012.02.017

16. Wolfley J. Biagaweit: Securing Water from the Mighty River in the Snake River Basin Adjudication. Ida Law Rev. 2016;52(313):23. https://doi.org/10.2139/ssrn.2766525

17. Water Policies for the Future: Final Report to the President and to the Congress of the United States by the National Water Commission. Washington, D.C.: National Water Commission; 1973.

18. Demsetz H. Toward a Theory of Property Rights. Am Econ Rev. 1967;57(2):347–59. http://www.jstor.org/stable/1821637

19. Rose CM. Energy and Efficiency in the Realignment of Common-Law Water Rights. J Leg Stud. 1990;19(2):261–96. https://doi.org/10.1086/467852

20. Anderson CL, Swimmer E. Some empirical evidence on property rights of first peoples. J Econ Behav Organ. 1997 May;33(1):1–22. https://doi.org/10.1016/S0167-2681(97)00018-8

21. Heather Smathers. Agency approves water deal with Gila River Indian Community. Rose Law Group Reporter. 2018 Nov 3;

22. Libecap GD. Distributional Issues in Contracting for Property Rights. J Institutional Theor Econ JITE Z Für Gesamte Staatswiss. 1989;145(1):6–24. https://www.jstor.org/stable/40751163

23. Perramond EP. Unsettled Waters: Rights, Law, and Identity in the American West. Vol. 5. Univ of California Press; 2018. 254 p.

24. Agrawal A, Goyal S. Group size and collective action: Third-party monitoring in common-pool resources. Comp Polit Stud. 2001;34(1):63–93. https://doi.org/10.1177/0010414001034001003

25. Coase RH. The Problem of Social Cost. J Law Econ. 1960;3(October):1–44. https://doi-org/10.1086/466560

26. Tashima AW. United States v. Walker River Irrigation District (CV 73-0127 RCJ).

27. Feller JM. The Adjudication that Ate Arizona Water Law. Ariz Law Rev. 2007;49:36.

28. Arizona Water Settlements Act. S. 437, Public Law 108-451 Dec 10, 2004 p. 3479–574.

29. Leonard B, Parker DP, Anderson TL. Land quality, land rights, and indigenous poverty. J Dev Econ. 2020 Mar;143:102435. https://doi.org/10.1016/j.jdeveco.2019.102435

30. Libecap GD. Chinatown Revisited: Owens Valley and Los Angeles—Bargaining Costs and Fairness Perceptions of the First Major Water Rights Exchange. J Law Econ Organ. 2009;25(2):311–38. https://doi.org/10.1093/jleo/ewn006

31. Falcone JA. U.S. Conterminous Wall-to-Wall Anthropogenic Land Use Trends (NWALT), 1974-2012. U.S. Geological Survey Data Series 948; 2015; 33p. plus appendixes 3-6 as separate files. https://doi.org/10.3133/ds948

32. Akaike H. A new look at the statistical model identification. IEEE Trans Autom Control. 1974 Dec;19(6):716–23. https://doi.org/10.1109/TAC.1974.1100705

33. Macpherson E. Beyond Recognition: Lessons from Chile for Allocating Indigenous Water Rights in Australia. 2017;40:40.

34. Edwards EC, Cristi O, Edwards G, Libecap GD. An illiquid market in the desert: estimating the cost of water trade restrictions in northern Chile. Environ Dev Econ. 2018 Dec;23(6):615–34. https://doi.org/10.1017/S1355770X18000220

35. Redsteer MH, Kelley KB, Francis H, Block D. Increasing vulnerability of the Navajo people to drought and climate change in the southwestern United States: Accounts from Tribal Elders. Spec Rep Indig People Marginalized Popul Clim Change Camb Univ Press Camb. 2013;

36. Key N, Burns C, Lyons G. Financial Conditions in the U.S. Agricultural Sector: Historical Comparisons. U.S. Department of Agriculture, Economic Research Service; 2019 Oct p. 36. Report No.: EIB-211.

37. McCool D. Command of the Waters: Iron Triangles, Federal Water Development, and Indian Water. Tuscon & London: University of Arizona Press; 1994. 356 p.

38. Grafton QR, Libecap GD, Edwards EC, O'Brien RJ (Bob), Landry C. A Comparative Assessment of Water Markets: Insights from the Murray-Darling Basin of Australia and the Western US. Water Policy. 2012;14(2):175–93. https://doi.org/10.2166/wp.2011.016

39. Nyberg J. The Promise of Indian Water Leasing. Nat Resour J. 2014;55(1):181–204. https://www.jstor.org/stable/24889754

40. Intergovernmental Agreement Between the Arizona Water Banking Authority and the Gila River Indian Community for the Development of Intentionally Created Surplus Firming Credits. 2019.

41. Shupe SJ. Indian Tribes in the Water Marketing Arena. Am Indian Law Rev. 1990;15(1):185–205. https://doi.org/10.2307/20068670

APPENDIX

A1: Summary Statistics

Table A1-1: Reservation-Level Summary Statistics, Mean and (standard deviation)

	Adjudicating	Non-Adjudicating	Total
Number of Reservations	81	145	226
ln(Prime Acres)	9.420	5.728	7.051
	(4.331)	(3.048)	(3.970)
Stream Order	5.319	2.75	3.668
	(2.251)	(2.139)	(2.498)
Off-Reservation County Population Growth Rate (%)	30.332	12.809	19.329
	(30.552)	(12.228)	(22.590)
POD Density (POD/mi2)	0.001	0.001	.001
	(.0013)	(0.002)	(.001)
1980-2010 mean April-Sept Precipitation Normal (mm)	24.805	30.094	28.198
	(14.794)	(21.808)	(19.715)
Credit (number of lending institutions to which reservations have access in 2018)	1.086	0.455	0.681
	(1.200)	(0.764)	(.987)
Casino operation prior to adjudication start=1 (dummy variable)	.086	0.503	.354
	(.283)	(0.502)	(0.479)
Reservation Per Capita Income (2000)	11,160.99	12,208.88	11,651.01
	(4175.923)	(5701.663)	(4957.478)

Notes: Standard deviation 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 Winters claims are adjudicated 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. Non-adjudicating reservations include those that have not initiated the adjudication process.

Table A1-2: Adjudication-Level Summary Statistics

	Mean	Standard Deviation	n
Number of Bargaining Parties	33.5	79.018	44
Unique Party Types	3.364	1.366	44
Democratic Congressional majority years as a percentage of adjudication years	51.264	27.559	44
Democratic Congressional majority in House and Senate in settlement resolution year=1 (dummy variable)	.417	.5	36
Basin Precipitation Spatial Coefficient of Variance	.343	.177	44
Casino operation prior to adjudication start=1 (dummy variable)	.0455	.211	44
Reservation Per Capita Income (2000)	10857.86	3695.07	41
Credit (number of lending institutions to which reservations have access in 2018)	1.386	1.224	44

A2. Adjudication Determinants

Table A2-1: 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)	0.0339***	0.0288**	0.0236*	0.0364***	0.0284**	0.0244*
	(0.0117)	(0.0112)	(0.0141)	(0.0138)	(0.0130)	(0.0144)
Stream Order	0.0412**	0.0431***	0.0233	0.0377*	0.0301	0.0193
	(0.0163)	(0.0155)	(0.0203)	(0.0197)	(0.0192)	(0.0208)
Off-Res. Pop. Growth Rate	0.00446***	0.00432***	0.00341***	0.00384***	0.00327***	0.00322**
	(0.00122)	(0.00115)	(0.00125)	(0.00130)	(0.00122)	(0.00125)
POD Density (POD/mi2)	0.0376	0.0411	0.0482	0.0369	0.0419	0.0437
	(0.0313)	(0.0278)	(0.0340)	(0.0364)	(0.0307)	(0.0344)
Precipitation (mm)	-0.00367***	-0.00361***	-0.00631***	-0.00448***	-0.00479***	-0.00636***
	(0.00140)	(0.00130)	(0.00159)	(0.00166)	(0.00149)	(0.00161)
BIA Region	0.0582***	0.0193	0.00629	0.0644***	0.00577	0.000641
	(0.0221)	(0.0220)	(0.0242)	(0.0242)	(0.0239)	(0.0241)
Casino Prior to Adj. Start		-0.294***	-0.429***		-0.416***	-0.451***
		(0.0550)	(0.0876)		(0.0797)	(0.0882)
Credit (2018)			0.0739*			0.0716*
			(0.0403)			(0.0404)
Reservation PCI 2000			-7.17e-07			-1.31e-06
			(8.44e-06)			(8.70e-06)
Constant	-0.242**	0.0314	0.341*	-0.201	0.292*	0.408**
	(0.0984)	(0.116)	(0.198)	(0.126)	(0.161)	(0.199)
Observations	216	216	138	154	154	135
R-squared	0.392	0.652	0.467	0.348	0.629	0.467

Notes: 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. Columns 2, 3, 5, and 6 contain additional controls for economic capacity: fractionated land area as a percentage of reservation area, number of lending institutions available to a reservation in 2018, and the presence of a casino prior to adjudication start. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

A3. Water Entitlement Predicted Outcomes

Table A3-1: Summary of AICc results for models relating AFY water entitlement outcomes with control variables

Model	K	n	AICc	AIC
M_1	1	36	123.1589	122.3589
M_2	2	36	115.5659	114.1866
M_3	**3**	**36**	**108.9994**	**106.8565**
M_4	4	36	110.3824	107.2713
M_5	5	36	111.5581	107.2504
M_6	6	36	114.4651	108.7051
M_7	7	36	117.5304	110.0304
M_8	8	36	121.3958	111.8306
M_9	9	35	125.7855	113.7855
M_{10}	10	35	130.6376	115.7805

Notes: K indicates the number of parameters included in each model specification, while n indicates the number of observations. AICc is the Akaike Information Criterion corrected for small sample size, and AIC is the Akaike Information Criterion. AIC and AICc are relative scores. We select the model (M_3) with the lowest AICc score.

Table A3-2: Predictors for each AICc Model

Model	Predictors
M_1	logged farmed acres (1974)
M_2	logged farmed acres (1974); logged reservation acres
M_3	**logged farmed acres (1974); logged reservation acres; mean basin precipitation**
M_4	logged farmed acres (1974); logged reservation acres; mean basin precipitation; percentage of adjudicated reservation area to state area
M_5	logged farmed acres (1974); logged reservation acres; mean basin precipitation; percentage of adjudicated reservation area to state area; logged prime acres
M_6	logged farmed acres (1974); logged reservation acres; mean basin precipitation; percentage of adjudicated reservation area to state area; logged prime acres; casino operation
M_7	logged farmed acres (1974); logged reservation acres; mean basin precipitation; percentage of adjudicated reservation area to state area; logged prime acres; casino operation; off-reservation decadal population growth rate prior to resolution
M_8	logged farmed acres (1974); logged reservation acres; mean basin precipitation; percentage of adjudicated reservation area to state area; logged prime acres; casino operation; off-reservation decadal population growth rate prior to resolution; stream order
M_9	logged farmed acres (1974); logged reservation acres; mean basin precipitation; percentage of adjudicated reservation area to state area; logged prime acres; casino operation; off-reservation decadal population growth rate prior to resolution; stream order; logged reservation population prior to resolution
M_{10}	logged farmed acres (1974); logged reservation acres; mean basin precipitation; percentage of adjudicated reservation area to state area; logged prime acres; casino operation; off-reservation decadal population growth rate prior to resolution; stream order; logged reservation population prior to resolution; BIA region

Notes: Table specifies dependent variables included in each AICc model specification. Variables specified in model 3 (M_3), which has the lowest AICc score, are included in our multilinear regression analysis that tests for determinants of AFY water entitlements.

Table A3-3: Upper and lower bounds on predicted water right allocations for completed and ongoing adjudications and actual settlement amounts, where settled.

Adjudication Agreements	Western States Water Council	Entitlement (AF/year)	Prediction (95% CI)	
			Lower Bound	*Upper Bound*
Timbi-Sha Shoshone		507	1,160	1,693
Lummi	21,072	685	2,122	4,279
Hualapai	386	694	7,447	14,998
Yavapai-Prescott	986	1,550	278	429
Las Vegas		2,000	691	998
Paiute (UT)		4,000	7,253	9,016
Fallbrook	11,408	4,994	6,281	8,058
Aamodt	62,517	6,467	14,600	18,044
Soboba	3,080	9,000	13,283	17,019
Fallon Paiute-Shoshone	13,612	10,588	25,767	34,300
Zuni	9,100	10,600	26,434	35,698
Taos	21,000	14,058	13,141	16,389
San Luis Rey	25,373	16,000	38,951	48,997
Rocky Boy's	131,400	20,000	34,000	39,960
Duck Valley (ID)	100,800	32,062	73,670	85,086
Fort McDowell	45,000	36,350	14,366	17,266
Jicarilla	36,288	45,646	43,816	57,784
Nez Perce	14,556	50,000	302,475	380,971
San Carlos	350,000	77,435	61,060	83,541
Tohono O'odham	12,284,300	79,200	291,664	397,159
Maricopa	85,000	85,000	42,732	56,647
Northern Cheyenne	486,500	91,330	48,077	57,252
Fort Apache	518,169	99,000	26,644	44,150
Duck Valley (NV)	95,425	114,082	111,093	127,774
Salt River	191,000	122,400	54,927	67,977
Ute		225,488	437,175	531,738
Warm Springs	7,493	325,786	29,600	41,502
Fort Belknap	211,400	477,408	154,820	184,161
Uintah	481,078	481,035	796,976	1,001,579
Pyramid Lake	4,258	520,000	80,724	104,368
Navajo (NM)		633,532	353,764	451,458
Gila	1,865,470	653,500	255,100	307,768
Fort Hall	563,290	711,862	328,934	398,497
Blackfeet	2,025,000	750,000	445,775	544,635
Crow	2,114,100	847,000	424,780	515,527
Fort Peck	1,050,472	1,050,472	831,944	1,060,762
Total	**22,829,553**	**7,609,731**	**5,401,524**	**6,767,480**

Ongoing Adjudications	Western States Water Council	Prediction (95% CI)	
		Lower Bound	*Upper Bound*
Yavapai-Apache	3,000	842	1,207
Tonto Apache		186	297
Bridgeport		402	579
Ramona		630	895
Benton Paiute		506	721
Yerington	4,725	388	560
Lone Pine	948	477	682
Havasupai	1,120	3,173	5,649
Big Pine		820	1,136
Santa Ana	17,610	17,531	20,298
Bishop		6,575	9,377
Zia	11,795	8,988	11,658
Cahuilla		36,496	47,923
Jemez	10,209	28,952	32,966
Hopi		50,082	73,994
Acoma	11,239	13,832	19,326
Navajo (AZ)[1]	15,000,000	290,863	457,859
Navajo (UT)		56,948	83,413
Tule River	510	2,850	4,626
Laguna	15,670	15,440	22,020
Walker River	25,000	107,488	131,191
Flathead	614,030	202,839	262,339
Coeur d'Alene	84,075	180,157	216,984
Umatilla	126,800	161,621	198,621
Agua Caliente		8,819	12,246
Total	**15,937,241**	**1,196,905**	**1,616,567**

[1]Western Water Council estimate includes all of Navajo Nation, Hopi Reservation and land under Hopi-Navajo joint ownership.