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

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

ABSTRACT

Sustainable management of common pool resources requires restrictions on use through either governmental control, common property organization, or property right allocation (Ostrom 1990). In the semi-arid western United States, surface waters are generally governed by the prior appropriation doctrine which allocates water based on the timing of initial claims. Streams across the west were fully allocated without regard to indigenous needs, but subsequent court rulings created a pathway for tribes to assert water rights. The water requirements of tribal settlements is a key source of uncertainty for understanding the sustainable use of western water. In addition, water right settlement has typically been the first step for tribes in developing water management plans that incorporate economic, social and ecological goals. This paper uses an economic framework to understand how water scarcity and bargaining costs influence American Indian Reservations' attempts to reclaim rights to local water resources. We find that tribes engage in negotiations with neighboring users only after water becomes scarce. The mean negotiation takes almost 25 years, with bargaining complexity a key determinant of their length. To date, 56 of 226 federally recognized reservations in the western US have completed the adjudication process, setting the current volume of adjudicated tribal rights at 9,656,065 acre-feet annually. The remaining 170 reservations have yet to adjudicate. Our estimates are just over 20% of previous estimates that suggested tribes could receive up to 45 million acre-feet annually (9).

[1] Tufts University, North Carolina State University, and Arizona State University respectively. Corresponding author: Eric Edwards (eric.edwards@ncsu.edu). Funding for this project was provided by USDA-AFRI 2015-69007-23190.

INTRODUCTION

Fierce competition over limited water resources is a defining characteristic of the western United States, where population growth, climate change, and persistent drought exacerbate the gap between water supply and demand (1–3) . Models predict that consumptive water use in western states will exceed water availability by 2030 (4,5). Since the late 1800's, many of the West's major rivers have been dammed, diverted, and appropriated for agriculture, energy, mining, and urban development. Surface waters in the western United States are generally governed by the prior appropriation doctrine, which assigns water rights based on the timing of the initial claim. The "first in time, first in right" chronological allocation of appropriative rights mandates that in times of shortage, senior water claims must be completely satisfied before junior claims are filled—senior water rights holders are guaranteed water in all but the driest years. In many western states the majority of appropriative water rights were assigned between 1850-1920 for irrigated agriculture, and by the mid-1900's most streams across the west had been fully allocated (4,6).

Like other resources at the time, surface water rights were appropriated without regard to the needs of Native American reservations (4,7,8). Around the time the first appropriative rights were being claimed, the US government was confining Native American tribes to reservations. Under treaty agreements signed with the US government, tribes were granted sovereignty over reservation land, to be held in trust. The federal government—in its legal role a trustee of tribal resources—neglected to file claims to water rights on behalf of tribes at the time reservations were created, and streams across the west were often fully allocated without regard to reservation needs (9). 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 (30, 95, 59–61), while the Yakama and Pyramid Lake Paiute reservations saw culturally and economically important fisheries affected by off-reservation irrigation diversions (11–14).

A 1908 ruling by the US Supreme Court (Winters v. United States), however, found that in creating reservations, the federal government had granted these and all tribes implicit rights to water "sufficient to fulfill the need of the reservation as a homeland" (15). The court ruling affirmed that the federal

government's trust responsibility obligated it to provide water rights, but did not grant appropriative rights or establish metrics to determine what quantity of *Winters Rights* tribes should receive. As western states experienced population growth in the 1950's and began to confront physical limitations of water supplies, reservations increasingly asserted claims to these federally reserved, but unfiled water rights.

When tribes do not hold formal water rights, they receive water only when it is not diverted by other appropriators, often leading to reduced water availability on reservations in times of scarcity or as off-reservation demand increases. To legally quantify Winters Rights, a reservation must either reach a negotiated settlement with the US government and neighboring water users to reallocate state appropriated water rights, or receive a judicial decree in state court. The status of Winters Rights claims across the western reservations is shown in the map in figure 1. Since the original ruling in 1908, only 56 of 226 federally recognized reservations in the western US have completed the adjudication process, setting the current volume of adjudicated Winters Rights at nearly 10 million acre-feet annually. However, little systematic research has been conducted about when tribes choose to settle, the duration of negotiations, or ultimate outcomes.

Because Winters Rights are not well studied, the outcomes of pending and future claims create considerable uncertainty for off-reservation water users, policymakers, and tribes. Water rights adjudication—resolving competing historical claims to water—is a complex bargaining process that has until recently not been studied extensively by social scientists (16). To this day the most commonly cited estimate of the potential amount of Winters claims of up to 45 million acre-feet per year—over three times the annual allocation of the Colorado River—comes from a rough 1983 estimate (17).

Filling this gap is important because reservations continue to play an increasing role in western water disputes. Womble et al. (2018) suggest that tribal surface and groundwater right adjudications may lead to more sustainable water use by resolving legal uncertainty and mitigating conflicts over water supplies (18). In recent years, adjudicated Winters Rights have played a key role in solving water allocation problems. In 2019 and 2020 the Gila River Indian Community will lease 200,000 acre feet to the Arizona Water Banking Authority as part of the Lower Colorado River Drought Contingency Plan to maintain lake

levels in Lake Mead. The Colorado Indian River Tribe, through a 2019 forbearance agreement with the Bureau of Reclamation and the State of Arizona, will fallow reservation farmland and redirect 50,000 annual acre feet of conserved water to Lake Mead (19). Consequentially, junior appropriative water rights holders, such as Central Arizona Project farmers, avoid water delivery curtailments that would have been triggered by falling lake levels (20). Further, while Winters Rights have historically applied to surface water, a 2017 ruling by the 9th Circuit Court established tribes' reserved rights to groundwater, thus suggesting another round of future adjudications under the Winters Doctrine (21–23).

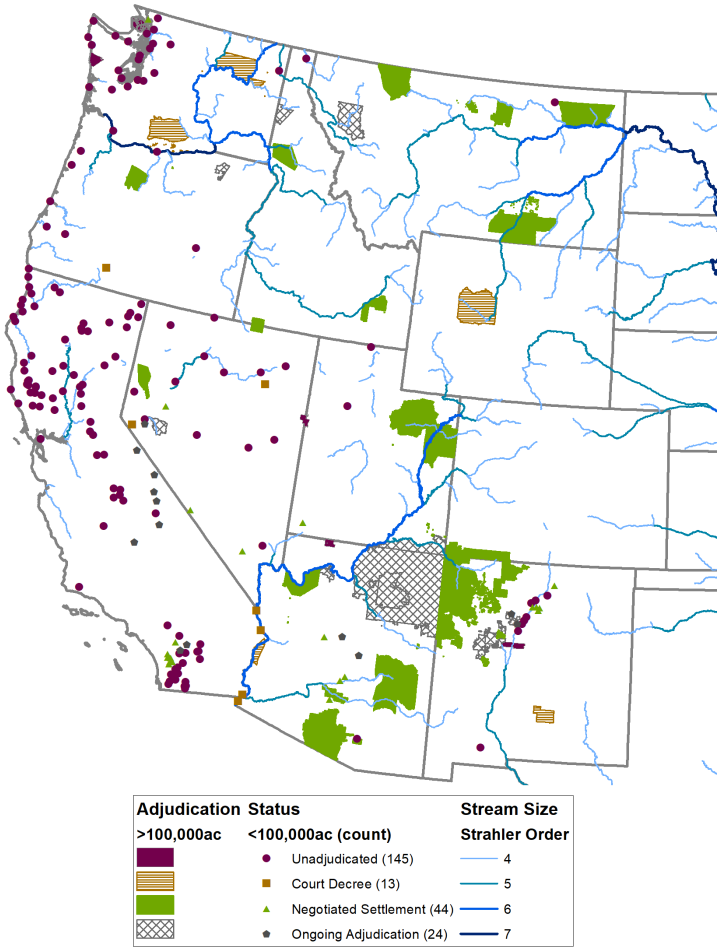

Figure 1. *Adjudication status of western reservations. Reservations under 100,000 acres are represented as symbols while those over 100,000 acres are represented according to reservation acreage. Navajo Nation and Duck Valley Reservation span multiple states, requiring separate adjudications.*

FRAMEWORK

We adopt the framework developed Ayres, Edwards, and Libecap (2018) for studying adjudication of groundwater rights to our setting and generate testable predictions about the causes and outcomes of Winters negotiations (16). Bargaining parties in Winters adjudications include reservations, the federal government, and neighboring appropriative water rights holders such as irrigation districts, municipal and industrial water users, energy companies, and individuals. While Winters v. United States (1908) found that tribes held federal reserved water rights, the allocation of state appropriative water rights had already occurred in many cases. In many cases this meant that the de facto water right allocation that was different than the expected outcome of a legal adjudication, and thus the need for bargaining between parties.

Adjudications, particularly when resolved through negotiated settlements, result in a combination of water entitlements and federal funding for tribes. The U.S. government's federal trust responsibility to reservations is a legal obligation to protect tribes' treaty rights, resources, and assets and to manage them in tribes' best interest (24). Many tribes have filed breach of trust claims against the U.S. government for damages they incurred when the government neglected to claim water on their 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 the implementation of settlement agreements

Generally, parties participate in a negotiated settlement when their expected benefits from doing so exceed their costs. However, the costs of reaching an agreement may be high, and these transaction costs limit the ability of parties to resolve competing claims (25). Tribes benefits from legally defining their priority rights to water because they acquire the ability to generate income from water through sales, leases, or productive use (26). For example, Navajo Nation in New Mexico has used partially decreed water rights to develop the Navajo Agricultural Production Industry, and the Gila River Indian Community signed a 2019 agreement to lease 18,000 acre-feet annually to the Central Arizona Groundwater Replenishment District for $97.5 million (27).

Physical water scarcity and the corresponding growth in the value of water, as in other resources, may increase the benefits of securing property rights (28). The value of surface water increases where precipitation and streamflow are scarce (Rose 1990,(29)). However, reservations also consider whether the advantages of water right security outweigh adjudication and litigation costs and risks associated with uncertain adjudication outcomes. Appropriative right holders participate in negotiations to resolve looming uncertainty about the quantity of tribal water rights and about how Winters rights will be accommodated (i.e. from which appropriative rights holders), or to avoid being litigants to proceedings in state courts (29). However, even where there appear to be positive net gains, agreement may not be forthcoming (29). Some users who do well under the status quo may oppose agreement, and the costs to bring them on board may be very high (30–32).

Difficulties in settlement increase with information asymmetries (25). Conflicting bargaining positions arise from different perceptions of fairness and disagreements over what each party feels it deserves (33). Specifically, irrigators maintain that the legal seniority of their water rights should be maintained even as tribes assert Winters claims, whereas tribes argue that irrigators have no inherent right to water, but rather have benefited from free use of the tribes' water (34). If the legal outcome of such cases is not clear because of limited precedent, opportunities for agreement may be reduced. 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 (35). Federal funding in negotiated settlements can help to defray high bargaining costs. In addition to payments to tribes, federal funding has been used to compensate irrigators for perceived losses, for instance in Arizona, negotiated settlements have included compensation for irrigation districts that forfeit water to satisfy newly defined Winters rights (36).

Increases in the number and heterogeneity of bargaining parties tend to increase the transaction costs of negotiation and make agreement less likely (37–41,29). 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 (42). Municipal water providers such as Metropolitan Water District

(MWD) in Los Angeles and the City of Phoenix in Arizona generally hold junior water rights but have substantial financial resources to devote to obtaining favorable adjudication outcomes. Where cities require secure, long-term water supplies but are junior to other water users, leasing provisions in settlements can provide tribes with reserved water rights and a potential revenue stream, while enabling cities to maintain access to water rights (43,44). In addition, increasing resource size and heterogeneity may raise costs of adjudication agreements (16,25). Larger surface water systems involve more users who may be more heterogeneous in their marginal valuation of water.

We analyze three stages of Winters right adjudications: initiation of adjudication; bargaining; and settlement. The complete set of adjudication start and resolution dates are shown in figure 2. We predict that all else equal, the probability that a reservation initiates the Winters right adjudication process, the start of the blue bars, increases when the benefits of water right security exceed the costs of acquiring, administering, and enforcing those rights. In the bargaining process, we expect that the duration (and thus cost) of resolving claims to Winters rights, the total length of the blue bar, increases with the size and heterogeneity of the water resource and the number of bargaining parties. And in terms of outcomes of the bargaining process, which we observe for the reservations with settlements dates of 2018 and earlier, we expect that the amount of water and federal funding allocated in settlement agreements is increasing in irrigable acreage, water endowment, and urban growth, and that these relationships can be used to predict outcomes for ongoing adjudications, the reservations with bars extending to 2019.

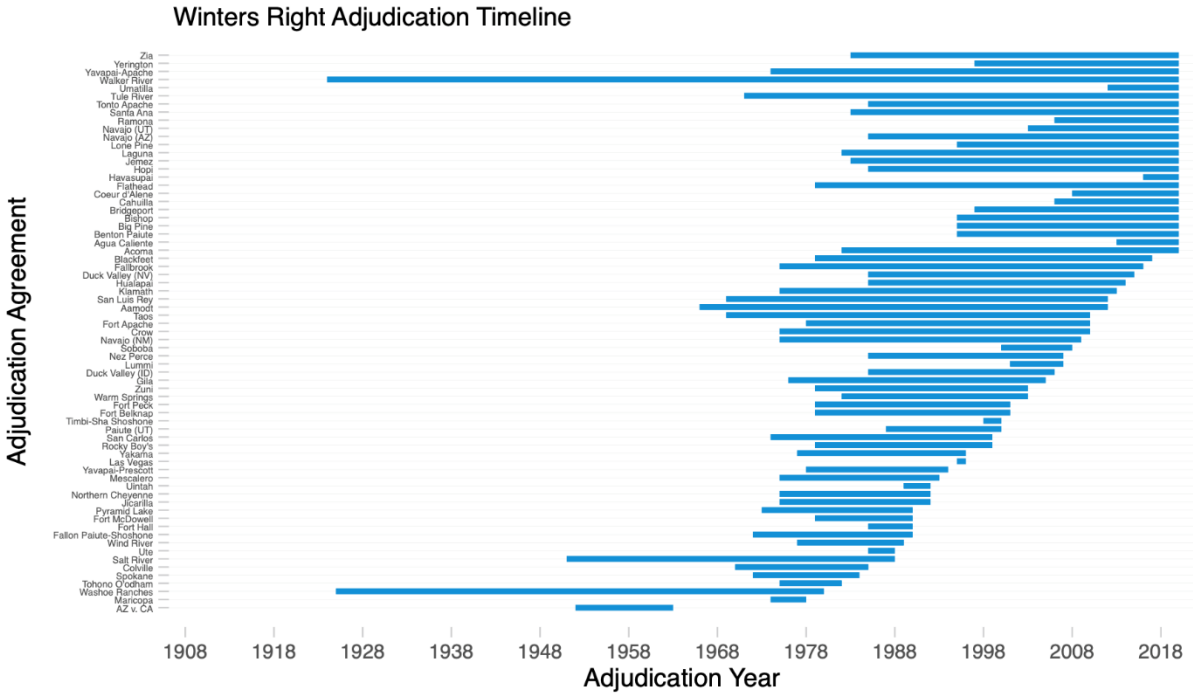

Figure 2. *Timeline of Winters rights adjudication negotiations and resolutions. Blue bars begin at date when adjudication effort begins and end when ratified. Bars extending to 2019 are ongoing.*

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 collect data on a cross-section of reservations according to whether they have initiated the process of legally defining Winters rights. Navajo Nation, which overlays Utah, New Mexico, and Arizona, is included as three distinct reservations, as the Nation must pursue separate adjudications in each state. Duck Valley Indian Reservation is similarly assessed as two separate reservations as it settled its Winters rights separately in Idaho and Nevada. We construct a binary dependent variable where reservations are assigned a value of 1 if they have started adjudicating, and a value of 0 if they have not started adjudicating.

Using a 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 costs and benefits: *prime agricultural acres*, the amount of land irrigation water could be put to productive 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. We model the probability of entering into the adjudication process as a function of these exogenous, reservation-level independent variables. Independent variables are either time-invariant or constructed to measure conditions prior to the start of adjudication. We run a logistic regression of current adjudication status on determinants of costs and benefits. Predicted slopes on parameter estimates indicate whether a variable increases or decreases the probability of initiating the adjudication process.

Next, conditional on having started the process of Winters right adjudication, we test for factors that increase the duration of the legal resolution of Winters claims. We use a Cox Proportional Hazard Model (CPH) to analyze the number of years required to resolve Winters rights. Conditional on having started the adjudication process, the hazard function represents the probability that the adjudication is completed. The CPH function is:

$$\lambda(t|X) = \lambda_0(t) * \partial(X ß')$$

$\lambda(t|X)$ represents the proportional hazard as a function of the number of years to complete adjudication conditional on covariates representing determinants of bargaining costs. X is a vector of covariates and λ_0 is the hazard function. The slope ß describes the effects of covariates on the hazard rate once a reservation has initiated adjudication—a negative slope on ß represents a longer adjudication process.

To perform the duration analysis a second set of data is collected for 44 adjudication agreements that have resolved Winters claims for 56 reservations—four of the adjudications (one court decree and three negotiated settlements) resolved Winters claims for multiple tribes. We select the adjudication agreement rather than the reservation as the unit of analysis for our examination of bargaining costs. 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. Primary data on litigated adjudications was collected from individual State and District court filings and from the Indian Claims Commission Decisions housed at the Oklahoma State University Library. We test covariates *number of bargaining parties*, *Democratic congressional majority*, *basin precipitation variance*, and *percentage urban land cover*. We expect the number and heterogeneity of water users to increase bargaining duration.

Finally, we assess the distribution of outcomes of 36 negotiated settlement agreements to reservations included in those settlement agreements. We assess two settlement outcomes – water entitlements and federal funding – as functions of characteristics of the bargaining problem faced by the tribe and other basin users. The unit of analysis is the adjudication agreement. 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 to the reservation. Measuring non-consumptive rights, as opposed to consumptive rights, more fully captures the volume of water available to tribes, particularly when those rights are used to maintain streamflow. 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 *2000-2010 percent change in urban land cover*, *reservation population*, *prime reservation acreage*, *reservation area*, *basin precipitation*, *the ratio of a state's already adjudicated reservation area to total state area*, a reservation's *BIA Self Governance status*, and *BIA region*. Winters claims are generally asserted based on irrigable acreage and future water needs. We anticipate that water entitlements are increasing with histories of agriculture and the potential to bring more land into production, and with larger reservation populations. We expect federal funding levels to increase as less water is available to satisfy tribal claims and as higher levels of reservation population and agriculture necessitate federally funded water projects.

RESULTS

Water Scarcity Drives Adjudications

We apply linear probability and logistic regression models to test the relationship between potential determinants of Winters adjudication benefits and the probability that a reservation has initiated the adjudication process. The results of several different specifications are provided in appendix (A3) and we discuss our findings generally here. The results corroborate that tribes pursue legal certainty in their water rights when the benefits of doing so are high relative to costs. Population growth rate in counties 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. 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, POD density is positively correlated with adjudication. Both results suggest reservations are more likely to adjudicate when water is scarce and therefore more valuable.

Prime farmland acreage reflects net adjudication benefits to tribes because legal precedent allows them to claim larger volumes of Winters rights based on irrigable acreage (r.3 of table 1). All else equal, reservations with incrementally higher prime farm acreage are anywhere from 10% more likely to twice as likely as their counterparts to pursue adjudication. Likewise, higher order streams are also positively correlated with adjudication (r.4 of table 1). The greater volume of water in high order streams suggests that tribes are poised to receive a greater volume of water per unit of adjudication costs.

Results on adjudication decisions are summarized in the top left panel of figure 3. Here, we plot the standardized probability of a reservation entering into adjudication as a function of a characteristics of that reservation, evaluated at the mean-level of all other variables. For instance, going from a reservation one standard deviation below the mean to one standard deviation above the mean in prime acres, stream order, or population growth increases the probability that the reservation has adjudicated by 40-50 percentage points. Alternatively, an increase in precipitation decreases the probability a reservation has entered into the adjudication process.

Bargaining Costs

Results from the CPH regressions on the years to resolve claims to Winters rights are shown in the appendix (A4). Despite the small number of observations, we observe statistically significant results across model specifications. All else equal, an increasing number of bargaining parties is highly correlated with a more protracted adjudication process (r.5 in table 1). These results are seen in the top-right panel of figure 3, which shows the duration of bargaining is expected to be longer for negotiations in the upper-quartile of number of bargaining parties, relative to those in the lower quartile. Litigation typically coincides with a higher number of bargaining parties than negotiation, as individual appropriative rights holders assert claims for water. Accordingly, these findings lend empirical strength to federal policy, legal analyses, and qualitative studies that advocate for negotiation over litigation as a strategy for reducing bargaining costs.

Table 1*. 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
Likelihood of Adjudicating	*All*		
	1	Potential depletion of reservation water supplies: *POD density*, *lack of* p*recipitation*	Increases
	2	Competing demands for water: *population growth*	Increases
	3	Opportunity costs to agriculture: *prime acres*	Increases
	4	Resource size: *stream order*	Increases
Years to Resolve	*Adjudicated*		
	5	Bargaining costs: *Number of parties*	Increases
	6	Congressional ratification: *Democratic majority*	Decreases
	7	Variance: *precip. variance*, *land use variance*	Ambiguous
Water Entitlement	*Settled*		
	8	*Year when settlement is finalized*	Decreases
	9	Congressional ratification: *Democratic majority*	Decreases
Total Funding	*Settled*		
	10	*Year when settlement is finalized*	Increases
	11	*Prime reservation acreage*	Increases

Urban land cover, a proxy for heterogeneous water demand, is associated with a slower adjudication process when controlling for a reservation's economic capacity (r.7 in table 1) but marginal increases in the spatial variance of rainfall within adjudicated basis, on average, corresponds to faster adjudication timeline, which was not expected within the analytical framework which predicted that

heterogeneous water distribution across basins complicates and therefore prolongs the adjudication process. On average, a higher percentage of years of Democratic congressional majority during the adjudication process is highly correlated with a more expedited adjudication process (r.6 in table 1), a finding supported by anecdotal account of tribes preferring to have settlement ratified by a Democratic congresses.

Outcomes

We use a regression model to analyze outcomes of 36 negotiated settlement agreements. Water entitlements per prime acre decrease over time as bargaining parties moved away from the PIA standard and as tribes conceded some Winters claims during the negotiation process in exchange for federal funding (r.8 in table 1). Conversely, the total adjusted federal funding per negotiated settlement was increasing over time (r.10 in table 1). Over time and on average, reservations receive a lower per prime acre water entitlement but more total federal funding.

Water entitlements are decreasing with the increasing percentage of years throughout the adjudication when Democrats hold a majority in both houses of Congress (r.9 in table 1). Consistent with the framework laid out previously. The other statistically significant predictor of total federal funding is a reservation's prime farmland acreage (r.11 of table 1). All else equal, each prime acre is correlated with a $139 increase in total funding.

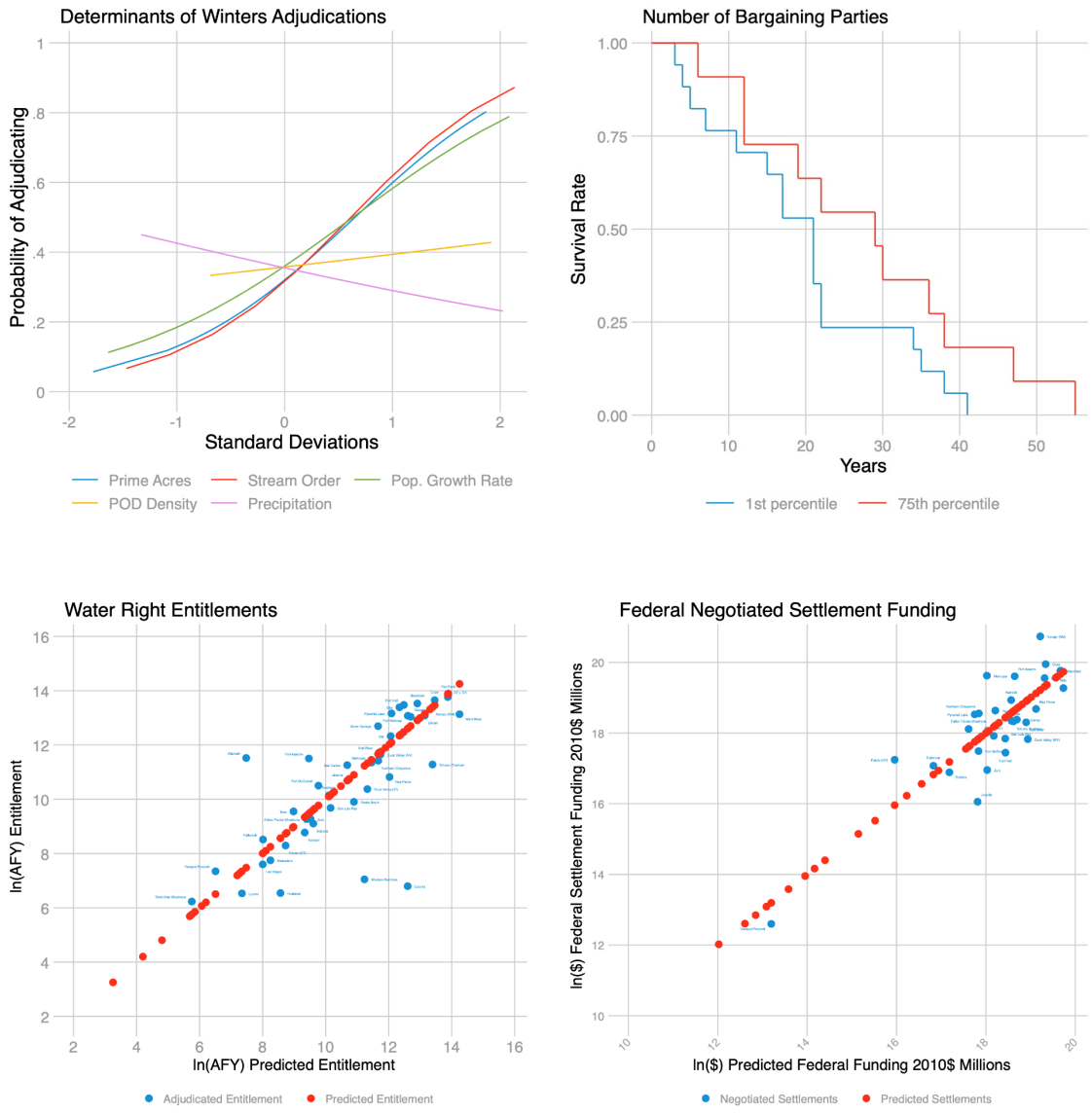

Figure 3. *Top-left- Predicted change in probability of a tribe undertaking adjudication for standardized changes in explanatory variable; all other variables are held at their means; specifications for these results are shown in table A3-1, column 1. Top-right- Kaplan-Meyer not parametric estimate of the survival function for the upper and lower quartile of adjudication number of bargaining parties. Bottom-left- predicted versus estimated water right entitlement outcomes of Winters adjudications (blue) and predicted outcomes of ongoing adjudications (red). Bottom-right- predicted versus estimated federal funding outcomes of Winters adjudications (blue) and predicted outcomes of ongoing adjudications (red).*

We use our models of outcome determinants to predict the outcomes of all remaining adjudications, but place particular emphasis on the 24 pending adjudications. Predictions results are shown in table 2 for both total water entitlements and anticipated federal settlement amounts. The total predicted amount of around 10 million acre-feet is considerably less than the predicted 45 million acre-feet annually that is the most commonly cited amount (9). The bottom left and right panels of figure 3 show the predicted outcomes, in red, along with actual negotiation outcomes relative to the amount the model predicts, in blue. While the model generally does a decent job predicting outcomes, each negotiation has a considerable amount of idiosyncrasy that affects the outcome. There is no established rule for what tribes will get, so there is likely to be considerable noise in the predictions. Because they are more similar to tribes that have already settled, we expected the reservations receiving larger amounts of water and funding are better predicted by our model. Those predicted to receive little water or funding, the bottom left of each figure, have few comparable reservations that have adjudicated and their agreements are highly uncertain.

DISCUSSION

Our findings contribute to an understanding of where and when Winters adjudications occur. Adjudications are more likely to occur in areas characterized by high-quality farmland and high-order streams. Likewise, our findings provide insight into how tribes and appropriative water rights holders may respond to time-variant factors, such as population growth and fluctuations in the physical water supply. Tribes enter into settlements as water values rise, as a response to physical and economic scarcity of water increasing.

In examining the duration of bargaining for Winters rights, the results are consistent with broader economic theory that the number resource users increases bargaining costs, delaying settlement. Tribes typically spend a number of years pursuing Winters adjudications in state courts prior to requesting negotiation teams ,and litigation involves more parties because everyone in the basin is involved. Once a tribe begins to pursue a negotiated settlement the number of parties typically falls and negotiations proceed

more rapidly, at least on average. One key implication is that moving, to the extent possible, to negotiate earlier in the adjudication process may reduce overall costs of resolving Winters claims.

Our results suggest that the future impact of unadjudicated Winters rights on off-reservation users may not be as severe as anticipated. Over time, reservations receive, on average, less water per prime acre, while the largest reservations, poised to receive the most water, have already adjudicated. As such, current estimates of unresolved claims to Winters rights, based on early negotiated settlements, overstated the entitlements that tribes are currently receiving. The only reliable predictor of federal funding is prime farm acreage, which is fixed for each tribe. However, the total water entitlement per settlement agreement is decreasing over time. Thus, although many tribes still have "implicit" rights to water, the value of these claims, at least in terms of wet water, have eroded over time. 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.

REFERENCES

1. Dettinger M, Udall B, Georgakakos A. Western water and climate change. Ecol Appl. 2015;25(8):2069–93.

2. Libecap GD. Water Rights and Markets in the US Semi-Arid West: Efficiency and Equity Issues. In Cambridge, MA; 2010.

3. Glennon R. Water scarcity, marketing, and privatization. Tex Law Rev. 2005;83(7):1873–1902.

4. Grantham TE, Viers JH. 100 years of California's water rights system: patterns, trends and uncertainty. Environ Res Lett. 2014 Aug 1;9(8):084012.

5. Tidwell VC, Moreland BD, Zemlick KM, Roberts BL, Passell HD, Jensen D, et al. Mapping water availability, projected use and cost in the western United States. Environ Res Lett. 2014 May 1;9(6):064009.

6. Brewer JPI, Stock PV. View of Beyond Extension: Strengthening the Federally Recognized Tribal Extension Program (FRTEP). J Agric Food Syst Community Dev. 2016;6(3):91–102.

7. Cosens B, Chaffin BC. Adaptive Governance of Water Resources Shared with Indigenous Peoples: The Role of Law. Water. 2016 Mar 11;8(3):97.

8. Blumm MC. Federal Reserved Water Rights as a Rule of Law. Ida Rev. 2016;52:369.

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

10. 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.

11. Wolfley J. Biagaweit: Securing Water From the Mighty River in the Snake River Basin Adjudication. Ida Law Rev. 2016;52(313):23.

12. Vonde AY, Bromley CM, Carter MM, Nygard SEH, Hensley HA, Orr MC, et al. Understanding the Snake River Basin Adjudication. Ida Law Rev. 52:171.

13. 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.

14. Sanchez L, Aylward B. Surface Water Markets in Nevada: the Truckee and Carson Rivers. Portland: Ecosystem Economics; 2016 p. 34.

15. Winters v. United States. 1908.

16. 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.

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

18. 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.

19. The United States of America, Through the Department of the Interior, Bureau of Reclamation, the State of Arizona, the Central Arizona Water Conservation District, and the Colorado River Indian Tribes to Fund the Creation of Colorado River System Water Through Voluntary Water Conservation and Reductions in Use During Calendar Years 2020-2022. 2019.

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

21. Pearce MJ, Glennon R. Transferring Mainstem Colorado River Water Rights: The Arizona Experience. 2007;

22. Colby BG, Thorson JE, Britton S. Negotiating Tribal Water Rights: Fulfilling Promises in the Arid West. University of Arizona Press; 2016. 216 p.

23. Richard C. Tallman. Agua Caliente Band v. Coachella Valley Water District. 2017.

24. Seminole Nation v. United States, 316 U.S. 286. 1942.

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

26. Anderson CL, Swimmer E. Some empirical evidence on property rights of first peoples. J Econ Behav Organ. 1997 May;33(1):1–22.

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

28. Demsetz H. Toward a Theory of Property Rights. Am Econ Rev. 1967;57(2):347–59.

29. Leonard B, Libecap GD. Collective action by contract: Prior appropriation and the development of irrigation in the western United States. J Law Econ. 2019 forthcoming;

30. Johnson RN, Libecap GD. Contracting Problems and Regulation: The Case of the Fishery. Am Econ Rev. 1982 Dec;72(5):1005–22.

31. Libecap GD, Wiggins SN. The Influence of Private Contractual Failure on Regulation: The Case of Oil Field Unitization. J Polit Econ. 1985;93(4):690–714.

32. Libecap GD, Wiggins SN. Contractual Responses to the Common Pool: Prorationing of Crude Oil Production. Am Econ Rev. 1984 Mar;74(1):87–98.

33. Colby BG. Bargaining over Agricultural Property Rights. Am J Agric Econ. 1995;77(5):1186–91.

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

35. A. Wallace Tashima. United States v. Walker River Irrigation District (CV 73-0127 RCJ). p. 31.

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

37. Olson M. The Logic of Collective Action: Public Goods and the Theory of Groups. Cambridge: Harvard University Press; 1965.

38. Ostrom E. Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge University Press; 1990. 308 p.

39. Libecap GD. Distributional Issues in Contracting for Property Rights. J Institutional Theor Econ JITE Z Für Gesamte Staatswiss. 1989;145(1):6–24.

40. Adhikari B, Lovett JC. Transaction costs and community-based natural resource management in Nepal. J Environ Manage. 2006 Jan;78(1):5–15.

41. Ruttan LM. Economic Heterogeneity and the Commons: Effects on Collective Action and Collective Goods Provisioning. World Dev. 2008;36(5):969–85.

42. Coase RH. The Problem of Social Cost. J Law Econ. 1960;3(October):1–44.

43. Nyberg J. The Promise of Indian Water Leasing. Nat Resour J. 2014;55(1):181–204.

44. Bovee B, Wolfley J, Teton E, Martin G. Tribal Water Marketing: An Emerging Voice in Western Water Management. Water Rep. 2016 Jul 15;(149):2.

45. Schaetzl RJ, Krist FJ, Miller BA. A Taxonomically Based Ordinal Estimate of Soil Productivity for Landscape-Scale Analyses: Soil Sci. 2012 Apr;177(4):288–99.

46. Bryan Leonard, Dominic Parker, Terry Anderson. Property and Poverty American Indian Reservations - DRAFT. 2017 Oct 6;

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

48. Donohew Z, Libecap G. Water Transfer Level Dataset. Bren School, UC Santa Barbara;

49. U.S. Government Accountability Office. Indian Irrigation Projects: Numerous Issues Need to Be Addressed to Improve Project Management and Financial Sustainability. Washington, DC: Government Accountability Office; 2006 Feb. (Report to the Chairman, Subcommittee on Interior and Related Agencies, Committee on Appropriations, U.S. Senate). Report No.: GAO 06-314.

50. U.S. Department of the Interior. Status Report | Land Buy-Back Program for Tribal Nations. 2014 Nov.

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 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 (45). We adapt the measure from Leonard et al (2018) to define prime farmland acreage as log of total reservation acreage where PI $\geq$9 (46). Schaetzl (2012) demonstrates that the PI on randomly selected agricultural sites for field crops in Michigan averaged 10.94 (SD $\pm$ 2.36) (45). 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 (47).

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.

Water Right Price: We assess the marginal value of water to off-reservation water users as the market price per acre-foot of water ($/AFY) in the year when the adjudication agreement was finalized. Using the Water Strategist Water Transactions Database, we construct the off-reservation marginal value of water by basin by year from 1987-2010 (48).

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.

Spatial variance of precipitation: Calculated as 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 (49).

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 (50).

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 worldcasinodirector.com. Casinos were first authorized in 1988 under the Indian Gaming Regulatory Act.

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.

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. We construct an additional measure of the percent change in off-reservation county urban land cover using 30mx30m resolution National Land Cover Data from 2001 and 2011.

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.

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)	9.421 (4.330)	5.727 (3.046)	7.051 (3.970)
Highest Stream Order (#)	5.321 (2.241)	2.74 (2.137)	3.668 (2.498)
Population Growth Rate (%)	29.99 (31.338)	12.604 (11.173)	18.949 (22.470)
POD Density (POD/mi^2)	0.001 (.0013)	0.001 (0.002)	.001 (.001)
Precipitation (mean)	24.949 (14.713)	30.013 (21.858)	28.198 (19.715)
BIA project (dummy)	.198 (.401)	1 (0)	0.071 (0.257)
Lending Institution in 2018 (dummy)	0.543 (.501)	0.324 (0.470)	0.403 (.492)
Casino Prior to Adj. Start	.074 (.264)	0.51 (0.502)	.354 (0.479)
Reservation PCI 2000	11168.24 (4148.087)	12216.75 (5746.38)	11651.010 (4957.478)
Fractionated Area (%)	18.491 (23.089)	24.642 (40.083)	22.016 (33.842)

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)	1.226***	3.166***	1.150*	1.232***	3.063***	1.151*
	(0.0784)	(1.186)	(0.0889)	(0.0842)	(1.161)	(0.0891)
Highest Stream Order (#)	1.325***	2.147	1.177	1.254*	2.102	1.148
	(0.137)	(1.084)	(0.1670)	(0.1460)	(1.0720)	(0.1660)
Off-reservation population growth rate	1.032***	1.142**	1.036***	1.030***	1.139**	1.036***
	(0.00964)	(0.0606)	(0.0133)	(0.0103)	(0.0602)	(0.0132)
POD Density (POD/mi2)	4.183e+122**	2.208e+171	2.194e+148*	1.415e+110*	4.26E+167	1.30E+139
	(5.955e+124)	(9.132e+173)	-4.40E+150	-2.13E+112	-1.75E+170	-2.59E+141
Precipitation (mm)	0.970**	0.950	0.956**	0.970**	0.951	0.957**
	(0.0141)	(0.0340)	(0.0213)	(0.0147)	(0.0338)	(0.0208)
BIA Region	1.426***	1.174	1.082	1.477***	1.227	1.049
	(0.183)	(0.587)	(0.1910)	(0.2080)	(0.6380)	(0.1880)
Lending Institution (2018)			1.748*			1.730*
			(0.5310)			(0.5270)
Casino Prior to Adj. Start			0.0621***			0.0602***
			(0.0419)			(0.0405)
Reservation PCI 2000			1			1
			(0.0000)			(0.0000)
Fractionate Area (%)		1.018			1.018	
		(0.0130)			(0.0130)	
Constant	0.00911***	1.25e-08***	0.126	0.0129***	1.79e-08***	0.182
	(0.00696)	(7.16e-08)	(0.1770)	(0.0119)	(0.0000)	(0.2610)
Observations	226	82	139	159	69	136

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)	0.0332***	0.0785***	0.0235**	0.0377***	0.0872***	0.0240**
	(0.00876)	(0.0146)	(0.0112)	(0.0105)	(0.0172)	(0.0114)
Highest Stream Order (#)	0.0385***	0.0294	0.0198	0.0324*	0.0205	0.0162
	(0.0139)	(0.0220)	(0.0187)	(0.0177)	(0.0268)	(0.0191)
Off-reservation population growth rate	0.00515***	0.00531***	0.00455***	0.00476***	0.00579***	0.00439***
	(0.00123)	(0.00172)	(0.00135)	(0.00139)	(0.00189)	(0.00135)
POD Density (POD/mi2)	33.38*	0.0214	39.03*	32.18	-8.699	36.52
	(19.40)	(28.38)	(23.06)	(23.00)	(30.84)	(23.32)
Precipitation (mm)	-0.00353**	-0.00422**	-0.00611***	-0.00445**	-0.00473**	-0.00614***
	(0.00154)	(0.00202)	(0.00219)	(0.00188)	(0.00225)	(0.00221)
BIA Region	0.0595***	0.0279	0.00725	0.0642***	0.0278	0.00214
	(0.0188)	(0.0313)	(0.0242)	(0.0221)	(0.0341)	(0.0245)
Lending Institution (2018)			0.0771**			0.0753*
			(0.0387)			(0.0390)
Casino Prior to Adj. Start			-0.426***			-0.445***
			(0.0818)			(0.0828)
Reservation PCI 2000			-1.66e-07			-8.73e-07
			(6.73e-06)			(6.80e-06)
Fractionate Area (%)		0.000449			0.000636	
		(0.00122)			(0.00132)	
Constant	-0.267***	-0.487***	0.292	-0.227*	-0.502***	0.354*
	(0.0903)	(0.146)	(0.185)	(0.122)	(0.179)	(0.189)
Observations	226	82	139	159	69	136

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	-0.00732**	-0.0135**	-0.00906***	-0.0160**
	(0.00303)	(0.00628)	(0.00322)	(0.00692)
Democratic Congressional Majority	0.0188**	0.0295***	0.0172**	0.0311***
	(0.00760)	(0.00806)	(0.00808)	(0.00884)
Basin Precipitation Variance	0.00238**	0.00318***	0.00277***	0.00371***
	(0.000963)	(0.00117)	(0.000993)	(0.00121)
% County Urban Land Cover (1980)	-0.00863	-0.00846	-0.0208*	-0.0210*
	(0.00868)	(0.00940)	(0.0112)	(0.0123)
Operated Casino Prior to Adj. Start			0.194	0.592
			(0.886)	(0.951)
Lending Institution (2018)			-0.378**	-0.340*
			(0.170)	(0.174)
Reservation PCI 2000		.00001		.000009
		(.00005)		(.00005)
Observations	44	41	44	41

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

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

	(1) Adj Duration	(2) Adj Duration	(3) Adj Duration	(4) Adj Duration
Bargaining Parties	-0.00593**	-0.0103**	-0.00774***	-0.0120**
	(0.00271)	(0.00485)	(0.00286)	(0.00492)
Democratic Congressional Majority	0.0199**	0.0313***	0.0191**	0.0339***
	(0.00807)	(0.00864)	(0.00841)	(0.00977)
Basin Size	1.80e-05	1.52e-05	2.75e-05**	2.98e-05*
	(1.24e-05)	(1.44e-05)	(1.30e-05)	(1.60e-05)
% County Urban Land Cover (1980)	-0.00740	-0.00893	-0.0188*	-0.0185
	(0.00890)	(0.00981)	(0.0106)	(0.0115)
Operated Casino Prior to Adj. Start			0.0507	0.141
			(0.866)	(0.905)
Lending Institutions (2018)			-0.427**	-0.418**
			(0.171)	(0.191)
Reservation PCI 2000		6.16e-05		8.45e-05
		(5.84e-05)		(6.04e-05)
Observations	44	41	44	41

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

A5. Adjudication Outcomes

Table 2: Multilinear Regression Estimated Effects on Negotiated Settlement Outcomes

	AFY Entitlement per Prime Reservation Acre	Total Federal Funding (2010$)	Federal Funding per Prime Reservation Acre
Year Settlement Finalized	-0.974*	7.702e+06*	659.1
	(0.553)	(4.035e+06)	(393.6)
Off Reservation $/AFY	-0.00466		
	(0.00795)		
Democratic Congress	-0.374**	1.763e+06	222.2*
	(0.173)	(1.220e+06)	(116.1)
Mean Basin Precipitation	-0.278	1.044e+06	108.7
	(0.293)	(2.158e+06)	(202.7)
Reservation: Basin Size Ratio	0.0748		-605.2*
	(0.473)		(315.3)
Prime Reservation Acreage		139.4**	
		(56.89)	
2000-2010 % Δ Urban Land Cover		8.432e+06	861.5*
		(5.060e+06)	(485.9)
Constant	1,983*	-1.552e+10*	-1.328e+06
	(1,110)	(8.118e+09)	(791,670)
R-squared	0.212	.338	0.215
Observations	33	36	35

A5-2. Adjudication Outcomes

Table 9 Multilinear Regression Estimated Effects on Total Negotiated Settlement

	ln(Federal Funding 2010$)	ln(AFY)
ln(2010 Reservation Population	0.842*	-0.0373
	(0.463)	(0.298)
2000-2010 %Δ Urban Land Cover	0.0312	0.0541
	(0.0397)	(0.0389)
Casino Prior to Adjudication Start		-0.101
		(1.243)
ln(farmed reservation acres in 1974)	0.818	0.719*
	(0.546)	(0.379)
ln(prime acres)	0.0897	-0.376*
	(0.251)	(0.210)
ln(precipitation)	-0.178	-0.552
	(0.618)	(0.680)
ln(reservation area)	-0.0675	1.164***
	(0.366)	(0.346)
ln(reservation:state area)		-0.110
		(0.0872)
ln(1974 farmed area)*ln(2010 res. Population)	-0.0725	-0.0410
	(0.0609)	(0.0418)
Self Governance		0.513
		(0.567)
Resolution Year	0.0351	
	(0.0217)	
Reservation:state area * Basin Precip	4.31e-08	
	(3.83e-07)	
BIA Region	0.0873	-0.128
	(0.194)	(0.208)
Constant	-61.24	8.144***
	(43.73)	(2.807)
Observations	28	36
R-squared	0.713	.824