Sharing a River: Bargaining Over Overlapping Claims

Tim Kelley, University of Wyoming, tkelley4@uwyo.edu

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Introduction

The Colorado River Doctrine establishes rules for allocating the Colorado River, but overestimates the river's flows, creating an overlap in users' claims. Users need to negotiate reductions to deal with this overlap. Basin states have struggled to reach agreements for the Colorado River. Motivated by the Colorado River, how do side payments and possible federal intervention intervention affect bargaining over a river's overlapping claims?

We describe an economic bargaining model and an experiment (an ultimatum game with outside options) to address this question. Our methods allow us to analyze how various institutions (side payments and third-party intervention) may affect sharing rules and cooperation when bargaining over a river. We predict that a threat of third-party (federal) intervention achieves more efficient outcomes. Side payments have no effect unless the outside option is changed from settling disagreements with contests (i.e., litigation) to settling disagreements with third-party intervention. The results from the model provide null hypotheses for an experiment.

Literature Review

Much of the river-sharing literature is axiomatic, focusing on identifying distributions that meet stability and fairness criteria while incorporating spatial characteristics of a river. We use non-cooperative game theory. However, we share similarities with the literature that employs a cooperative game theory approach (e.g., Kilgour and Dinar, 2001; Ambec and Sprumont, 2002; Gudmundsson et al., 2019) by incorporating side payments and spatial characteristics of a river. Side payments create an incentive for transferring water potentially increasing welfare. Without side payments, there may be an increase in demand for property rights redistribution. Where we differ from the literature is our inclusion of third-party intervention. Our model and experiment enable us to observe how alternative institutions affect behavior.

Our contribution to the river-sharing literature is an experiment. Our experiment is a variation of a Coasean bargaining experiment - an experiment that test the theorem from Coase (1960). Experimental economists have tested the Coase theorem starting with Hoffman and Spitzer (1982), who found that subjects with perfect information can negotiate efficient outcomes using side payments. Coasean bargaining outcomes and efficiency are sensitive to the rules of the bargaining scenario, such as including transaction costs or property right insecurity(e.g., Rhoads and Shogren, 1999; Cherry and Shogren, 2005. Our experiment is most similar to Friesen et al. (2023), who has parties bargain after incurring costs for acquiring the initial allocation of property rights. We differ from Friesen et al. (2023) because the costly effort is only realized in the event of a disagreement, and agents do not incur transaction costs. The outside options are threats that may affect player behavior in our experiment.

Outside options can be a deterrent rather than a facilitator of bargaining. We contribute to the experimental literature by examining how various outside options influence behavior. Subjects in ultimatum games with an outside option are more likely to disagree in the lab (Knez & Camerer, 1995). Outside the lab, empirical evidence suggests that external agencies can disrupt bargaining and cooperation (Ostrom and Gardner, 1993). Ansink and Weikard (2009) model bargaining over overlapping claims to a river and found that third-party intervention causes conflict and obstructs bargaining under certain conditions.

Model

In this section, we present our theory for bargaining over overlapping water claims. We describe the theory for four institutional arrangements: bargaining with and without side payments when the outside option is litigation i.e., a court case, and bargaining with and without side payments when the outside option is federal intervention.

Our spatial representation of a river is a line. Water flows unilaterally from its source in state 2 down to state 1. State 2 is mountainous, and state 1 is a valley; state 1 is more productive with the water. Both states have a historic claim c_i with $i = 1, 2$, to an amount of water. Because of changes in precipitation, the river can no longer provide both states their historic claims. The states need to reduce their collective use by R. There is no clear property right that determines the reductions. The states need to negotiate an agreement over how much each will reduce their use r_i so that $r_1 + r_2 = R$.

The states use the water as an input for production. The states recieve the same price p for their outputs and generate rents. After the states reduce their water use, their rents are

$$\pi_1 = pa(c_1 - r_1)^{\alpha} \tag{1}$$

$$\pi_2 = p(c_2 - r_2)^{\alpha}, \tag{2}$$

where $\frac{d\pi_i}{dr_i} < 0$ and $\frac{d^2\pi_i}{d^2r_i} < 0$. We assume all water used for production is consumed. State 1 is more productive than State 2; $a > 1$.

We model negotiations as an ultimatum game with perfect information. State 1's use of water has historically been prioritized; State 2 would reduce its use during temporary water shortages.[1] The presumption that priority may still apply to this long-term reduction gives state 1 bargaining power in negotiations. State 1 is the first mover in our ultimatum game. State 1 offers to reduce its use by r_1, where $0 \leqslant r_1 \leqslant R$. State 2's

[1]The prior appropriation doctrine is used to allocate surface water in the Western United States. This doctrine establishes a priority system based on the principle of first use. During a drought, senior users, who were the first to use the water, face no reductions, while junior users have their allotment of water curtailed.

proposed reduction is $r_2 = R - r_1$. State 2 accepts or rejects the proposal. If State 2 is indifferent between accepting and rejecting an offer, we assume State 2 accepts. We model this bargaining process under two different outside options. The outside options represent the threat that if the two parties are unable to agree on reductions, the reductions will be decided by a court case (modeled as a contest) or federal intervention (modeled as an exogenous split).

A Social Planner chooses reductions for State 1 and State 2 that maximize the total rents of the water remaining after reductions. The socially optimal reduction for State 1 r_1^* is implicitly defined as

$$-\alpha pa(c_1 - r_1)^{\alpha-1} + \alpha p(c_2 - R + r_1)^{\alpha-1} - \nu_1 + \nu_2 = 0, \tag{3}$$

where ν_1 is the multiplier for an upper-bound constraint and ν_2 the multiplier for a non-negativity constraint for r_1. For an interior solution, $\nu_1 = 0$ and $\nu_2 = 0$. The first term in (3) is the marginal cost of reduction, the lost rent from State 1 reducing its use by a unit of water, and the second term is the marginal benefit of reduction, the rent gained from State 2 not having to reduce its use by that unit of water.

Bargaining with Threat of a Court Case

The status quo is that if the states are unable to reach an agreement through bargaining, then they use the courts to decide who reduces their water use. We model the court process as a contest. Following Dixit (1987), the contest is between two risk-neutral players (the states) who choose effort or fighting inputs f_i to determine their probability of winning the contest (the court case). The probability of winning is dependent on the ratio of fighting inputs

$$\rho_1 = \frac{\phi f_1}{\phi f_1 + f_2}, \tag{4}$$

$$\rho_2 = \frac{f_2}{\phi f_1 + f_2}. \tag{5}$$

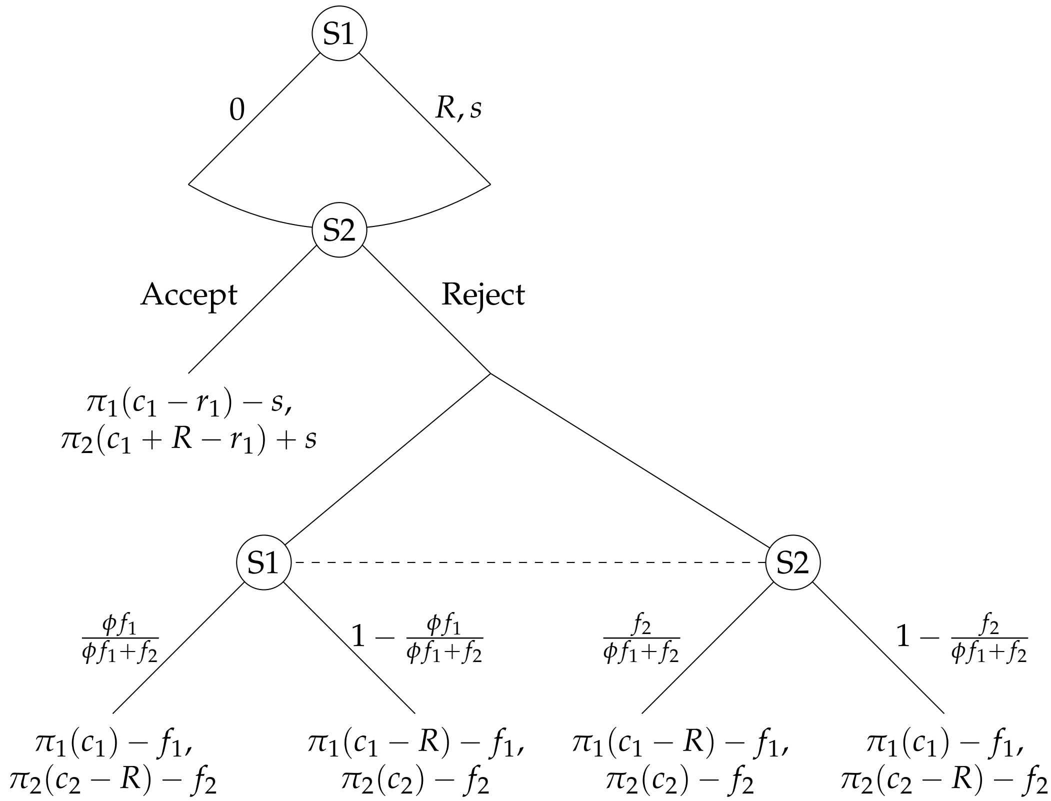

FIGURE 1. Game tree for bargaining with side payments with the threat of a contest. Bargaining without side payments takes the same form but State 1 makes an offer only over R, and so payoffs do not include s.

We assume State 1 is favored in the contest, $\phi > 1$, because of the precedent of priority. If a state wins the court case, it wins the right to keep its full claim c_i. If a state loses the court case, it's responsible for the full reductions $c_i - R$. The states simultaneously choose their level of effort and maximize their expected payoff from the contest. The optimization problems for State 1 is

$$\max_{f_1} \frac{\phi f_1}{\phi f_1 + f_2}(pac_1^{\alpha} - f_1) + \big(1 - \frac{\phi f_1}{\phi f_1 + f_2}\big)(pa(c_1 - R)^{\alpha} - f_1) \tag{6}$$

and for State 2 is

$$\max_{f_2} \frac{f_2}{\phi f_1 + f_2}(pc_2^{\alpha} - f_2) + (1 - \frac{f_2}{\phi f_1 + f_2})(p(c_2 - R)^{\alpha} - f_2). \tag{7}$$

We construct the following reaction functions for States 1 and 2 using the first-order conditions from (6) and (7):

$$f_1 = \frac{1}{\phi}\left(\sqrt{\phi f_2(pac_1^\alpha - pa(c_1 - R)^\alpha)} - f_2\right), \tag{8}$$

$$f_2 = \sqrt{\phi f_1(pc_2^\alpha - p(c_2 - R)^\alpha)} - \phi f_1. \tag{9}$$

The intersection of (8) and (9) is a Nash equilibrium and defines the optimal effort for both states (f_1^*, f_2^*) in the contest.

When bargaining without side payments, State 2's decision rule is to accept an offer if

$$p(c_2 - R + r_1)^\alpha \geqslant \frac{f_2^*}{\phi f_1^* + f_2^*} pc_2^\alpha + (1 - \frac{f_2^*}{\phi f_1^* + f_2^*})p(c_2 - R)^\alpha - f_2^*. \tag{10}$$

State 2 accepts a proposal for reductions if the rents from it are greater than or equal to its expected payoffs of the court case. State 1 knows State 2's decision rule. State 1 sends an offer to reduce its use by the smallest reduction r_1^* that State 2 would accept,

$$r_1^* = \left(\frac{f_2^*}{\phi f_1^* + f_2^*} c_2^\alpha + (1 - \frac{f_2^*}{\phi f_1^* + f_2^*})(c_2 - R)^\alpha - \frac{f_2^*}{p}\right)^{\frac{1}{\alpha}} - c_2 + R. \tag{11}$$

The Nash equilibrium of the status quo game is for State 1 to propose reductions $\{r_1^*, R - r_1^*\}$, and for State 2 to accept the offer.

We now allow for side payments while keeping the outside option as the courts. The potential payoffs for the two states bargaining over reductions and a side payment are

$$\pi_1 = \begin{cases} pa(c_1 - r_1)^\alpha - s & \text{agreement over } R, s, \\ \frac{\phi f_1^*}{\phi f_1^* + f_2^*}(pac_1^\alpha) + (1 - \frac{\phi f_1^*}{\phi f_1^* + f_2^*})(pa(c_1 - R)^\alpha) - f_1^* & \text{disagreement on } R, s, \end{cases}$$

$$\pi_2 = \begin{cases} p(c_2 - R + r_1)^\alpha + s & \text{agreement over } R, s, \\ \frac{f_2^*}{\phi f_1^* + f_2^*} pc_2^\alpha + (1 - \frac{f_2^*}{\phi f_1^* + f_2^*})(p(c_2 - R)^\alpha) - f_2^* & \text{disagreement over } R, s. \end{cases}$$

Side payments are constrained, $s \geqslant 0$. The side payment allows State 1 to pay State 2 to be responsible for more of the mandatory reduction. State 2 will accept a proposal (reduction and side payment) if its payoff is greater than or equal to its outside option. State 1 maximizes its rents knowing State 2's decision rule. State 1 would not offer a side payment greater than the minimum needed for an agreement.[2] The minimum side payment is

$$s_n = \frac{f_2^*}{\phi f_1^* + f_2^*} p c_2^\alpha + (1 - \frac{f_2^*}{\phi f_1^* + f_2^*}) p (c_2 - R)^\alpha - f_2^* - p(c_2 - R + r_1)^\alpha. \tag{12}$$

The minimum side payment pays the difference between State 2's expected value of the court case and the value that State 2 generates with the water remaining after the proposed reduction. The necessary side payment decreases when State 1 increases its reductions. More effort spent in the contest f_2^* reduces the size of the side payment.

State 1's optimal reduction from its claim is given by

$$\max_{r_1} pa(c_1 - r_1)^\alpha - \frac{f_2^*}{\phi f_1^* + f_2^*} p(c_2)^\alpha - (1 - \frac{f_2^*}{\phi f_1^* + f_2^*}) p(c_2 - R)^\alpha + f_2^* + p(c_2 - R + r_1)^\alpha \tag{13}$$

subject to

$$R \geqslant r_1 \geqslant 0, \tag{14}$$

$$\frac{f_2^*}{\phi f_1^* + f_2^*} p(c_2)^\alpha + (1 - \frac{f_2^*}{\phi f_1^* + f_2^*}) p(c_2 - R)^\alpha - f_2^* - p(c_2 - R + r_1)^\alpha \geqslant 0. \tag{15}$$

State 1's first-order condition is

$$-\alpha pa(c_1 - r_1)^{\alpha-1} + \alpha p(c_2 - R + r_1)^{\alpha-1} - \nu_1 + \nu_2 - \nu_3 \alpha p(c2 - R + r_1)^{\alpha-1} = 0. \tag{16}$$

When there is a positive side payment, $\nu_3 = 0$ and the first-order condition is the same as the social planner. State 1 chooses a socially optimal reduction in this scenario. When

[2] See appendix for Kuhn-Tucker analysis.

$\nu_3 > 0$, it decreases the marginal benefits of reduction, and State 1's proposed reduction r_1 is smaller than the socially optimal r_1. The subgame perfect equilibrium for State 1 is to propose $(r_1^*, R - r_1^*)$ with a side payment $s_n(r_1^*)$ and for State 2 to accept.

Bargaining with Threat of Federal Intervention

We now present our theory when the outside option is external intervention. We assume that if the states are not able to reach an agreement through bargaining, then the Federal Government intervenes and imposes equal reductions, $\frac{1}{2}R$, on both states. We describe a sensitivity analysis for the sharing rule and the credibility of federal intervention later in the results section.

State 2 will not accept a reduction greater than that which reduction the Federal Government threatens to impose. When bargaining without side payments, the reduction that satisfies state 2's decision rule is $r_1 = \frac{1}{2}R$. Similarly, State 1 would not offer to reduce any more than it would have to if the Federal Government intervened. The subgame Nash equilibrium when bargaining without side payments and the outside option is federal intervention is for State 1 to offer $\{\frac{1}{2}R, \frac{1}{2}R\}$ and for State 2 to accept.

Now, moving to our last institutional arrangement bargaining with an outside option of federal intervention. If State 1 can offer a side payment when bargaining, the states' payoffs are

$$\pi_1 = \begin{cases} pa(c_1 - r_1)^\alpha - s & \text{agreement over } R, s, \\ (pa(c_1 - \frac{1}{2}R)^\alpha & \text{disagreement over } R, s, \end{cases}$$

and

$$\pi_2 = \begin{cases} p(c_2 - R + r_1)^\alpha & \text{agreement over } R, s, \\ p(c_2 - \frac{1}{2}R)^\alpha & \text{disagreement over } R, s. \end{cases}$$

Changing the outside option changes the equation for the necessary side payment. The minimum side payment from State 1 is

$$s_e = p(c_2 - \frac{1}{2}R)^{\alpha} - p(c_2 - R + r_1)^{\alpha}. \tag{17}$$

State 1 offers a proposal that maximizes its rents subject to a positive side payment, $s_e \geqslant 0$, and an upper and lower bound on reductions, $R \leqslant r_1 \leqslant 0$. When bargaining with side payments, State 1's first-order condition is

$$-\alpha pa(c_1 - r_1)^{\alpha-1} + \alpha p(c_2 - R + r_1)^{\alpha-1} - \nu_1 + \nu_2 - \nu_3 \alpha p(c_2 - R + r_1)^{\alpha-1} = 0 \tag{18}$$

The first-order condition is the same as the social planner when there is a positive side payment and $\nu_3 = 0$. The subgame Nash equilibrium is for state 1 to offer to reduce its use from its claim by r_1^* with a side payment $s_e(r_1^*)$ and for State 2 to accept when bargaining with side payments and the threat of federal intervention.

Numerical Results

We use numerical results to gain insight into how heterogeneity affects bargaining and side payments. We compare the efficiencies of the treatments. The parameters for our base case are the following: the states' claims are $c_1 = 10$ and $c_2 = 6$; the overlap in claims is six units of water $R = 6$; State 1 is favored in the contest $\phi = 2$; State 1 is more productive $a = 2.5$; production has diminishing returns $\alpha = 0.5$; price per unit of production is $p = 4$. Some of State 1's water is secure, four of their units are not bargained over, in our base case. State 2 has its whole claim bargained over in the base case of our numerical analysis. We run sensitivity analyses for our results to the size of the reduction, the difference in productivity, the favoritism in the court case, the size of the difference between the two claims, the sharing rule the Federal Government imposes, and the credibility of federal intervention.

TABLE 1. Results from the four games with parameters $c_1 = 10$, $c_2 = 6$, $R = 6$, $\alpha = 0.5$, $a = 2.5$, $\phi = 2$, $p = 4$. Optimal fighting inputs were $f_1^* = 2.4244$ and $f_2^* = 2.0438$. Under the reduction column, r_1^* is listed first and r_2^* is in parentheses.

Treatment	**Efficiency**	**Reductions**	π_1	π_2
Social Planner	1.00	1.38 (4.62)	29.361	4.7
Court	.95	0.05 (5.95)	31.54	0.8615
Court w/ Payments	.95	0.05 (5.95)	31.54	0.8615
Fed. Intervention	.98	3 (3)	26.45	6.93
Fed. Intervention w/ Payments	1.00	1.38 (4.62)	27.1306	6.93

The Social Planner provides the baseline for economic efficiency. Bargaining with side payments and the threat of federal intervention is efficient under our initial parameters. All other treatments result in inefficient agreements. Although still inefficient, federal intervention without side payments is more efficient than both court case treatments. Side payments did not increase efficiency when the outside option was the court case because State 1 does not use them. State 1 does not offer a side payment because State 2's expected value from the court case is so low; if State 2 wins, its rents from production are small, and if State 2 loses, they have no water for production and expended effort. A small reduction from State 1 allows State 2 to use the water for production when State 2's marginal productivity is the highest. A small reduction is sufficient to make State 2 indifferent between an agreement and a court case, which makes a side payment unnecessary. The model's results suggest side payments do not increase efficiency without changing the outside option from the status quo. Side payments will not improve the efficiency of the reductions in the use of the Colorado River unless they are accompanied by a threat of federal intervention.

The two states prefer different outside options. State 1's payoffs are highest when the outside option is a court case. State 1 prefers bargaining over reductions under this institutional arrangement. State 1 is indifferent between bargaining with and without side payments under this arrangement because its rents are the same. Conversely, State

2's rents are the highest when the outside option is federal intervention. State 2 prefers this institutional arrangement. Our assumption about State 2's decision rule is reflected in Table 1. State 2's rents are the same with and without side payments. State 2 is indifferent between bargaining with or without side payments. An interpretation of the model's results is that a lack of side payments in the Colorado River negotiations is because neither party's rents increase from using side payments since the current outside option is a court case. Without gains, neither party has a desire to change how they bargain.

The reductions from our model satisfy a bankruptcy rule. All players received an amount between 0 and their full claim. But subjects in an experiment in a similar bargaining scenario might find these splits unsatisfactory, given that rents are substantially different for the two parties. We use an experiment to test our theory and search for facts about Coasean bargaining over a loss with an endogenous and exogenous outside option in the next section.

Experiment

We describe a future experiment in the remaining sections. We present hypotheses, a power analysis, and an experimental design. The court case is referred to as a contest, and federal intervention is referred to as an exogenous split in the remaining sections specific to the experiment. The primary outcomes that we are interested in are whether a game resulted in an agreement or disagreement, the efficiency of an agreement (the reductions r_1 and r_2), the size of side payments, the size of side payments given reductions, and the effort spent in the contest when there is a disagreement. We test the following null hypotheses:

(1) The percentage of bargains that result in an agreement is equal across all treatments.

(2) The efficiency of bargained outcomes without side payments is equal to the efficiency of bargained outcomes with side payments for the contest treatment.

(3) Bargained outcomes for the exogenous split with side payments treatment are more efficient than the bargained outcomes of the other treatments.

(4) A player's effort in the court case is equal to the Nash equilibrium effort.

Experimental Design

We describe the experimental design in this section. The experimental instructions are context-neutral. The treatments are two outside options (contest or exogenous split) and two types of bargaining (bargaining with or without side payments). Subjects are tasked with bargaining over reducing their use of a resource that is an input for production in each game. Subjects start with an endowment of the resource, i.e., their claim. They bargain over how much of their claim each will reduce to meet a specified reduction. No communication is allowed between subjects, and all subjects interact through a program using oTree (Chen et al., 2016).

The experiment is a repeated one-shot game. In every session, subjects play 20 games in total. Subjects know each other's payoffs. For all treatments, subjects are provided a payoff matrix that shows their payoffs and the other subject's payoffs for different combinations of the resource. We follow a process similar to Shogren and Baik (1992) for the contest treatments; subjects receive an additional payoff matrix that shows expected payoffs for combinations of efforts in the contest. We tell the subjects that we use a logit probability that is weighted in the proposer's favor. Subjects know the imposed split for the exogenous split treatments.

	Outside Option	
Type of Bargaining	Contest w/o side payment (Status Quo)	Exogenous Split w/o side payment
	Contest w/ Side payments	Exogenous Split w/ Side Payment

FIGURE 2. The four treatments for the experiment. Contest without side payments is the status quo for settling disputes.

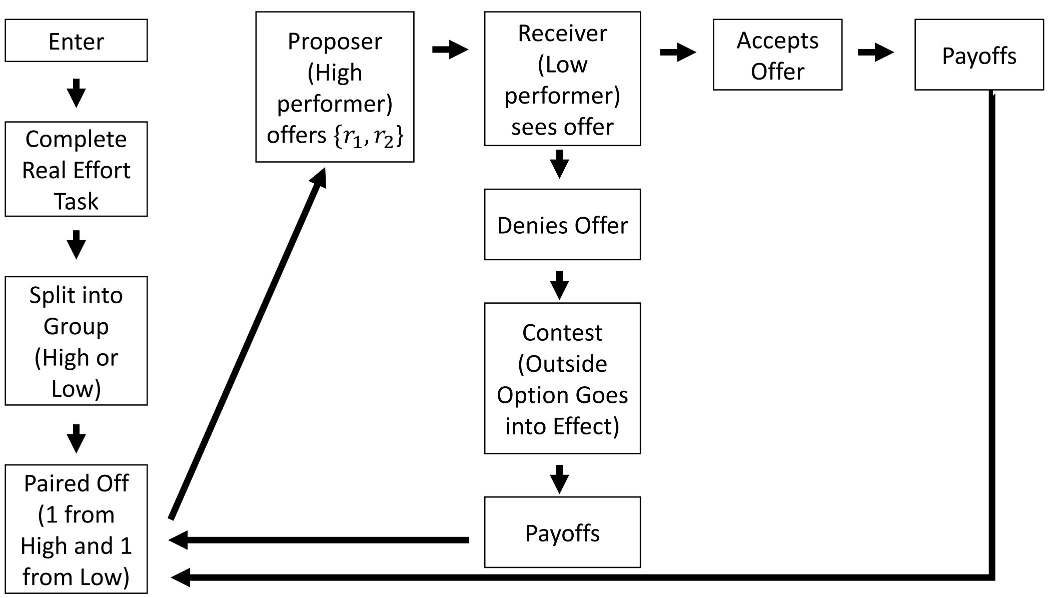

FIGURE 3. Flowchart of the experimental design - a repeated one-shot ultimatum game. Treatments that change bargaining allow the proposer to make an offer over quantities reduced and a side payment. Treatments changing the outside option change the contest to an exogenous split.

The experiment proceeds as follows. Upon entering the lab, each subject is assigned a computer. Subjects are provided instructions for the status quo game to follow as a recording reads the instructions. Subjects then answer questions to check their comprehension of the instructions and the consequences of actions in the experiment. These questions check that players understand the heterogeneity in the game and how to use their payoff matrices. Any additional questions from subjects will be answered at this time.

The subjects complete a real-effort task (a counting game) to determine their role in the experiment. The subjects' performance in the counting game is evaluated by the number of attempts and the speed at which the game is completed. We split the subjects into two groups. The half that performs better will play as proposers (the first mover with a larger endowment) for the entire session. The other half plays as respondents (the second mover with a smaller endowment) for the whole session. Subjects are told their assigned role before any bargaining occurs. One player is drawn from the proposer pool, and the other is drawn from the respondent pool randomly when rematching bargaining pairs between games.

All subjects play the status quo game to start. The proposer is prompted to offer a proposal for the quantities each will reduce. Reductions are limited to the values on their payoff matrices. After the proposer submits their offer. The respondent receives it and is then prompted to accept or refuse the offer. If the respondent agrees, reductions and their associated payoffs are awarded according to the offer's terms. If there is disagreement, the players enter a contest to determine how the resource is allocated. Players simultaneously dedicate an amount up to their show-up fee to increase their probability of winning the contest. Players receive the same show-up fee that they can dedicate to the contest. The show-up fee will be larger than our prediction of optimal effort (the calculated Nash equilibrium) in the contest. After the players choose their effort in the contest, a winner is selected. The winner of the contest does not have to reduce their use of the resource, and the loser of the contest is responsible for all reductions.

Next, the players either continue playing the baseline game ten more times, or they will play the game for one of the treatments ten times. If subjects are in a session where they play one of the treatments, new instructions are provided explaining the treatment and alteration to the game mid-session. Subjects bargain over quantity reduced and a side payment. Players are constrained to only offering reductions that are specified on their payoff matrix. However, the side payment is allowed to range from 0 to the maximum rent that the proposer receives if his proposal is accepted. The proposer can give everything earned from the agreement to the respondent, but the proposer cannot give more. When changing the treatment to bargaining with the outside option of an exogenous split, the subjects share reductions based on an equal loss-sharing rule, where both parties are responsible for half of the total reduction amount if there is a disagreement.

Subjects will take a questionnaire at the end of the session. The questionnaire data is used to control for confounding variables relating to risk aversion and social preferences in the analysis.

Conclusion

We presented a model for bargaining over water with and without side payments under two different outside options. The model predicts that when there is a shortage of water and a need for states to bargain, a threat of federal intervention achieves more efficient outcomes. Side payments will have no effect unless the outside option is changed from settling disagreements with litigation (the status quo) to settling disagreements with federal intervention. The results from our model provide null hypotheses for future experiments. Future experimental results will provide insight into how people respond to changing the institutions that characterize how water is bargained over in the Colorado River Basin.

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