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Contests for Shares of an Uncertain Resource

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Abstract: The process of allocating rights to resources can be viewed as a contest: parties compete with each other for the right to claim a larger allocation. In some situations, the amount of the resource that is available to allocate may be unknown when parties are competing for shares and perhaps not realized until contestants actually attempt to claim their shares of the resource. For example, fishing quotas may be awarded based on estimated fish populations, but if there are fewer fish than anticipated, those who are last to harvest may not be able to fill their quota. We model contests of this form and test the predictions of the model using a controlled laboratory experiment. The general result, supported by both theory and experimental data, is that participants compete less intensively for shares of the resource when uncertainty regarding the size of the prize is resolved later in the process.

Keywords: Contests with Uncertain Prizes, Fisheries, Experimental Economics
JEL Codes: C7, C9, D7, Q2

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Introduction

Recently, there has been considerable theoretical and experimental attention on contests, where parties compete for the right to claim a share of a prize (e.g., Dechenaux et al., 2015; Sheremeta, 2011). Applications vary from election campaigns to patent races and brand advertising to lobbying efforts and political processes for awarding natural resources (Boyce, 1998; Fudenberg et al., 1983; Krueger, 1974; Snyder, 1989; Tullock, 1980). The effort and resources dedicated to competing for a share of a prize rather than to productive activities are commonly referred to as rent-seeking behavior (Bhagwati, 1982; Krueger, 1974; Posner, 1975; Tullock, 1967). Such behavior has been shown to occur in many institutional settings and to have large social losses (e.g., Angelopoulos et al., 2009; Cowling and Mueller, 1978; Torvik, 2002).

In the literature, it is typically assumed that the contestants know the value of the prize, or at least that the sum of the potential entitlements equals the available prize (see Sheremeta, 2019). However, there are settings in which this assumption may not hold because the amount of the prize is unobserved and shares to the prize are rewarded sequentially. For example, farmers secure rights to sequentially extract from an irrigation canal (Janssen et al., 2011a; Ostrom and Gardner, 1993). If water flow is less than expected when entitlements were determined, those farmers who extract last may not be able to claim any water. A similar phenomenon can occur in bankruptcy filings, where creditors are prioritized and some may be left unable to recoup losses if the assets turn out to be worth less than anticipated.

In this paper, we study a generalized version of a contest in which players compete for the right to a share of a prize when the size of the prize is uncertain and claims to the prize are filled sequentially. We develop a theoretical model that extends conventional proportional-prize contest models (Cason et al., 2010; Tullock, 1980) and generates a set of testable hypotheses under varying assumptions regarding the timing of when the size of the prize is realized. We test these hypotheses in a laboratory setting with an experimental design that uses the certainty of the prize (known or unknown) and the timing in which the prize is realized as treatments.[1] An important distinction between our paper and the previous literature is that we focus on the effect

[1] The positional asymmetry in a sequential claim setting is distinct from asymmetry in cost or ability that have been studied previously (see Konrad (2009) for an overview of previous theoretical treatments of asymmetry).

of an exogenously uncertain prize, whereas other papers have considered uncertainty in a different dimension by comparing winner-take-all and proportional prize contests (e.g. Chowdhury et al., 2014, Cason, et al., 2020, Masiliūnas 2020) with a known fixed prize.[2]

Our theory and motivation align with the circumstances of fishermen, who compete for harvest from a stock of unknown size (Laukkanen, 2003; McKelvey and Golubtsov, 2006). Indeed, intense user group competition and a highly variable prize are common features of many fisheries around the world (Hilborn et al., 2005; Huang and Smith, 2014). This is illustrated, perhaps, nowhere better than the salmon fisheries of the Kenai Peninsula in Alaska. There are varied user groups: commercial, sport, and personal-use fishermen. Each group invests significant time and money to compete for fish before and during the season. Pre-season lobbying is important for each user group, particularly sport and commercial, for establishing their share of the total allowable catch. The catch, or the prize, can be significant, but shares of the catch are regulated and depend on nature and the degree of competition with other users. Salmon abundance, particularly Sockeye salmon (a.k.a. Red salmon), is highly variable and difficult to predict (Schoen et al., 2017).

A particular feature of a salmon fishery is that harvesting is sequential due to the spawning habits of the species. Salmon spend their adult lives in the ocean. But on their way to spawn, salmon swim up-river in pulses over a short time period during the summer and early fall; salmon spawn in smaller tributaries and so all fishing is regulated to occur downstream of spawning areas. Different types of users operate in distinct areas, which the fish pass through in a single direction. Competition begins in the salt-water commercial fishery, as salmon converge at the mouth of river systems, and extends upriver where sport and subsistence/personal-use fishing occurs. Downstream and saltwater harvesters typically have a distinct advantage over

[2] In winner-take-all contests, the contest winner claims the entire prize with some probability, p, whereas in proportional prize contests, each player receives a share, p, of the prize. Thus, a proportional prize contest replaces the lottery each player faces in a winner-take-all contest (receive value V with probability p and 0 otherwise) with the expected value of that lottery (pV) conditional on the bids of all players, which determines p. There is at least one paper, Öncüler and Croson (2005), which considers a contest with an uncertain prize. In Öncüler and Croson (2005), the contest winner only receives the specified prize with a probability that depends on the contest winner's bid in the contest. Thus, their contest can be viewed as having a fixed prize and a modified contest success function in which the prize may not be claimed by anyone. By contrast, the uncertainty regarding the prize that we consider is exogenous to the actions of the players.

upstream users, particularly in low-abundance years. In high-abundance years, regulators adjust up allowable catch during the season to avoid "over-escapement" —i.e., too many fish escaping up-river to spawn—and mid-season adjustments often provide heterogeneous benefits.[3] As in other lobbying settings, Kenai River watershed users spend a considerable amount of resources trying to influence the State's Board of Fish and other agencies for favorable treatment. Ongoing declines in the important Chinook salmon (a.k.a. King salmon) fishery has also led to intense lobbying efforts by sport fishermen, who generally attribute the decline to a "bycatch" (i.e., incidental catch of Chinook salmon) problem with the commercial fishery.

While our theory is motivated by the salmon fishery, the experiments are neutrally framed so the implication of our results are more general and can be directly compared with other contest experiments. Similar to other studies, we find that subjects over-spend relative to predicted amounts in all treatments. In symmetric treatments, when subjects invest prior to the prize amount being determined, we find that player order doesn't matter as lobbying effort doesn't depend on bidding position as predicted by theory. In asymmetric treatments, when the sequential nature of the claims is such that prize collection order should impact behavior, we find that those whose claims are filled later invest less than those whose claims are filled earlier, consistent with theoretical predictions. Further, uncertainty is found to reduce overall effort, and when potential resources are capped (e.g., a limit on harvests that is less than the available resource), subjects invest less effort on average. Finally, when resources aren't capped and allocations are awarded before subjects know the amount of the available resource, the total amount of lobbying decreases. Our theoretical and experimental findings therefore suggest that when allocations are rewarded sequentially, rent-seeking behavior could be partially subdued by constraining lobbying effort to occur before the size of the prize is determined or announced.

[3] Too many fish spawning results in too many fry competing for limited resources in the river system. As a result, smolt (who go to the ocean) are less healthy or less abundant compared to smolt in seasons with more sustainable spawning levels.

Theoretical Model

Consider the following stylized setting in which three risk neutral players A, B, and C desire to harvest a resource, R, which is a random variable.[4] For simplicity, we assume $R \sim U[0, M]$, where M is the natural maximum of the resource. The nature of harvesting the resource is such that A harvests before B, who in turn harvests before C. For simplicity, we assume that harvesting is costless to each player and that the marginal value of each unit harvested is constant and normalized to one. Without some intervention, player A would harvest the entire resource leaving none for B or C to harvest. In such a situation, a benevolent government could choose to allocate the resource through a political process. Specifically, we assume that the players engage in costly Tullock-style lobbying in order to be awarded a permit to harvest a specified amount (Tullock, 1980). Let L_i denote the lobbying effort of player i, where $i \in I = \{A, B, C\}$ and let P_i denote player i's permitted amount.[5] The sequential nature of the harvest means that player A's actual harvest will be $H_A = \min\{P_A, R\}$. Player B's actual harvest will be $H_B = \min\{P_B, R - H_A\}$ and player C's actual harvest will be $H_C = \min\{P_C, R - H_A - H_B\}$. Player i's profit function is given by $\pi_i = H_i - L_i$.[6]

For reasons that will become apparent, we assume that the government sets a target $T \leq M$ specifying the maximum amount of the resource that can be allocated through the lobbying process. That is, the actual amount of the resource that is permitted to be harvested, $\sum_i P_i$, has two constraints, one natural and one political, and thus equals $\min\{R, T\}$.

Optimal lobbying efforts and equilibrium outcomes depend on when the resource R is realized. If R is known when the government acts, then permits can be based on both R and T. But, if R is unknown, then permits are based only on the target T, which could exceed the

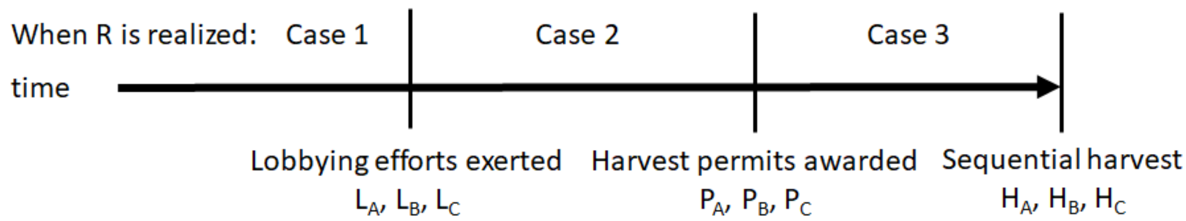
[4] Appendix 1 contains more general derivations, which allows for risk averse players and provides numerical solutions for risk averse subjects with constant relative risk averse preferences.

[5] Lobbying efforts, for instance, could be directed toward influencing the government or on influencing public opinion with the intent of influencing the policy maker.

[6] Modelling strategic behavior in an irrigation dilemma, as is done in the common pool resource literature, is similar, yet differs from our approach. In that literature, players make decisions in two stages: in stage one, an investment decision is made that determines the size of R, and in stage two, sequential extraction decisions are made until R is depleted (Janssen et al., 2011a, 2011b; Ostrom and Gardner, 1993). In contrast, R is exogenous in our model (determined by nature) and differs from an extraction target of T. Lobbying effort made in stage one yields harvests in stage two based on R, T, and a player's position in the sequence.

available resource, R. There are three separate cases to consider as depicted in Figure 1. In all cases, it is assumed that players know the government's policy with regards to T.

Figure 1. Sequence of Events



Case 1: R Known Prior to Lobbying and Permit Awards

If the government is willing for the entire realized resource to be allocated (i.e. $T = R$) then the situation becomes a standard symmetric Tullock contest. Player i's profit function becomes $\pi_i = s_i R - L_i$, where $s_i = L_i / \sum_{j \in I} L_j$. It follows that the equilibrium lobbying effort is $L_i^* = 2R/9$, and as a result, $P_i^* = R/3$. In this case, the sequential nature of the harvest does not matter because the sum of the permits equals R, and thus, each player can harvest the permitted amount, P_i, with certainty.

If the government set a target $T = \bar{T} < R$, then there would be some resource left over after the permitted harvests were collected.[7] A government might want to do this for a variety of reasons (e.g. sustainability of the resource, strategic reserves, etc.). Alternatively, the government could allow the final player to simply keep the residual $R - \bar{T}$. Whether the final player is a residual claimant or not would not impact the optimal lobbying effort. If player C is not a residual claimant, then player C's profit would be $\pi_C = s_C \bar{T} - L_C$. If player C is a residual claimant, then player C's profit would become $\pi_C = s_C \bar{T} - L_C + R - \bar{T}$. The two first-order conditions would be identical, and thus, the equilibrium lobbying effort would be $L_i^* = 2\bar{T}/9$ and each player is guaranteed to receive his permitted harvest.

Notice that the case of $\bar{T} < R$ differs from the previous result where $\bar{T} = R$ only in that the size of the known prize for which the players are lobbying has changed from R to $\bar{T}$. Treating the last player as a residual claimant would be reasonable if it was not practical for earlier players

[7] We assume that the government is benevolent and would not knowingly allocate more of the resource than what is available; thus, we do not consider the case where $T > R$.

to harvest again (such as salmon that move systematically) or if the final player valued the unused resource (such as an environmental group wanting to maximize the remaining amount of the resource).

Case 2: R Known After Lobbying but Before Permit Awards

Again, assuming the government will fully allocate the resource to the players (i.e., the government will set $T = M$), this problem is again a symmetric Tullock contest, but with an uncertain prize.[8] Player i would maximize the expected profit function of the form $E(\pi_i) = s_i E(R) - L_i$ and the optimal lobbying effort would be $M/9$ for each player given the assumption of a uniform distribution for R so that $E(R) = M/2$. In equilibrium, each player will harvest one third of the realized resource. As in case 1, the sequential nature of the harvest does not impact equilibrium lobbying efforts as $\sum_i P_i = R$.

If the government sets $T = \bar{T} < M$, then the government target may or may not bind when permits are awarded. In this case, Player i's expected profit would be $E(\pi_i) = s_i \left[\frac{\bar{T}^2}{2M} + \frac{\bar{T}(M-\bar{T})}{M}\right] - L_i$ and the resulting optimal lobbying effort would be $L_i^* = 2\left[\frac{\bar{T}^2}{2M} + \frac{\bar{T}(M-\bar{T})}{M}\right]/9$, where the term in brackets is the expected total amount of the resource to be awarded through lobbying efforts. As in case 1, if $T = \bar{T} < M$, then there may be some of the resource left over. If the last player were a residual claimant on this portion of the resource, it would not change the equilibrium outcome and would only represent a (random) transfer to the final player, just as it did in case 1. Here too, the sequential nature of the harvest does not impact behavior as $\sum_i P_i = \min\{R, T\}$, the amount available to be harvested.

Case 3: R Known After Permit Awards

In this case, permits are awarded based on the target T (i.e., $P_i = s_i T$). Because T is set before R is realized, T could exceed R. Thus, it is possible that $\sum_i P_i > R$ and not every player is able to harvest the permitted amount. The profits to the three players are

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[8] This policy is effectively the same as the government promising to set $T = R$ once R is realized. A similar construction could be done for case 1, where the government sets $T = M$ to use the full resource or sets $T = \bar{T} < M$, which could result in either the full resource being used or not, but in case 1 players would know this outcome prior to lobbying.

$\pi_A = \int_0^{s_A T} r \frac{1}{M} dr + s_A T \int_{s_A T}^{M} \frac{1}{M} dr - L_A$

$\pi_B = 0 \int_0^{s_A T} \frac{1}{M} dr + \int_{s_A T}^{s_A T + s_B T} (r - s_A T) \frac{1}{M} dr + s_B T \int_{s_A T + s_B T}^{M} \frac{1}{M} dr - L_B$

$\pi_C = 0 \int_0^{s_A T + s_B T} \frac{1}{M} dr + \int_{s_A T + s_B T}^{T} (r - s_A T - s_B T) \frac{1}{M} dr + s_C T \int_T^M \frac{1}{M} dr - L_C$.

For player A, the first term in the profit function reflects the possibility that the realized resource may be below his permitted amount, in which case he would only be able to harvest the realized amount. The second term in the profit function reflects the outcome when the available resource exceeds his permitted amount. For player B, the first term reflects the possibility that there may be an insufficient amount of the resource for player A to harvest his permitted amount, thus leaving nothing for player B. The second and third terms reflect the possibilities that player B's permitted harvest can be partially and fully fulfilled, respectively. The three terms for player C are similar to those for player B. Notice that if player C is a residual claimant then player C's profit would have an additional term of $\int_T^M (r - \mathrm{T}) \frac{1}{M} dr$, but this term would not depend on the lobbying effort of any player and would therefore not impact the equilibrium lobbying efforts or the permitted harvest amount of any player.

The resulting first order conditions for A, B, and C, respectively are

$$\frac{L_B + L_C}{(L_A + L_B + L_C)^2} T \left[1 - s_A \frac{T}{M}\right] - 1 = 0$$

$$\frac{({L_A}^2 + L_A L_C + L_B L_C)}{(L_A + L_B + L_C)^3} \frac{T^2}{M} - \frac{L_A + L_C}{(L_A + L_B + L_C)^2} T + 1 = 0$$

$$\frac{L_A + L_B}{(L_A + L_B + L_C)^2} T - \frac{(L_A + L_B)^2}{(L_A + L_B + L_C)^3} \frac{T^2}{M} - 1 = 0$$

These equations do not lead to nice closed-form solutions for the equilibrium lobbying efforts; however, it is possible to solve them numerically, as is done in Appendix 1.

Experimental Design

Experimental Treatments

To explore the behavioral impact of sequential harvesting, we conducted a laboratory experiment with 6 treatments, summarized in Table 1. The experiment used neutral language and did not refer to lobbying or the harvesting of resources. Instead, subjects bid for prizes. The treatments included one in which the prize was known prior to the players bidding for their shares of it (case 1). Specifically, we set $R = T = 120$ and refer to this treatment as *Fixed Prize* (Treatment 1). In this treatment, the equilibrium bid is **26.67** for all three players. The *Fixed Prize* treatment is similar to a standard Tullock contest experiment, and thus serves as a means for comparing our subject pool and procedures to previous studies.

In Treatments 2 and 3, subjects bid prior to the prize amount being determined, but the amount of prize that each player is permitted to claim is determined after the size of the prize is realized (case 2). These two treatments differ in terms of T, the maximum amount of the random prize that can be claimed. In Treatment 2, *Full Uncertain Prize*, $T = M = 240$ so that the full amount of the realized prize can be claimed. The expected value of the claimable prize is 120 in this treatment, just as in *Fixed Prize*, and the only difference between *Full Uncertain Prize* and *Fixed Prize* is uncertainty of the prize amount. This comparison allows us to directly investigate the impact of having prize uncertainty separate from the impact of sequential harvesting. As discussed previously, this uncertainty should not impact behavior if players are risk neutral. Thus, the equilibrium bid is **26.67** in *Full Uncertain Prize* for each of the players. In Treatment 3, the *Partial Uncertain Prize*, we set $T = 120$ (with $M = 240$) and explain to subjects that any portion of the realized prize $R > 120$ is “unavailable” and only amounts less than or equal to 120 are “available.” For risk neutral players, this should lead to a decrease in bids, as the expected value of the claimable prize is reduced to 90, and thus, the equilibrium bid is **20** for all three players.

As demonstrated in our theoretical model, the sequential nature of the claims does not impact behavior or outcomes in cases 1 or 2 so that all three players are strategically symmetric. Thus, we refer to *Fixed Prize*, *Full Uncertain Prize*, and *Partial Uncertain Prize* as the symmetric treatments.[9] In case 3, which includes Treatments 4-6, the sequential nature of the claims is such that prize-collection order should impact behavior, and hence, we refer to those treatments as the *asymmetric treatments*. Specifically, we consider three treatments in which the claimable prize is not known until players attempt to collect their awarded amounts (i.e., after permits are awarded).[10]

Asymmetric Full Uncertain Prize (Treatment 4) is similar to *Full Uncertain Prize* in that $T = M = 240$, but differs from it in that the available prize is not known when the maximum amount each person can claim is determined. After the variable prize is realized, the prize is allocated sequentially to player A, then player B, and then to player C, up until the point that R is fully allocated. Consequently, all players may not always receive their full permitted allocation. For this treatment, the equilibrium bids for players A, B, and C are **30**, **30**, and **0**, respectively, because player C finds it optimal to drop out of the lobbying competition. The intuition for this result is that there is a sizeable chance there is an insufficient amount of the resource available to satisfy the permits of A and B, and thus, C is likely to receive nothing. This result is distinct from standard simultaneous Tullock contests where a player should always invest a strictly positive amount.

Asymmetric Partial Uncertain Prize (Treatment 5) is similar to *Partial Uncertain Prize (Treatment 3)* in that $T = 120$, but differs in that the available prize is not known when the maximum amount each person can claim is determined. Like Treatment 4, in Treatment 5 the prize is allocated sequentially to player A, then player B, and then to player C up until the prize R is fully allocated or until the threshold T is reached. In this treatment, the equilibrium bids for players A, B, and C are **23.07**, **20.07**, and **13.46**, respectively. Capping the maximum amount of the resource that can be harvested in total increases the chance that enough of the resource is available after A and B harvest that player C is willing to compete.

The final treatment is *Residual Claimant (Treatment 6)*. This treatment is identical to *Asymmetric Partial Uncertain Prize* (Treatment 5) except that if $R > T = 120$, then player C is awarded the additional $R - 120$. The residual claim should not have any bearing on equilibrium

[9] These treatments are symmetric because the structure makes them equivalent to simultaneous harvest games. As such, these treatments were presented as having simultaneous prize claims.
[10] Depictions of the numerical best-response functions and equilibrium lobbying efforts for Treatments 4, 5, and 6 can be found in Appendix 1.

behavior, and thus, the equilibrium bids for players A, B, and C are **23.07**, **20.07**, and **13.46**, respectively.

Given that the main research focus of this paper is the impact of the sequential nature of claiming the resource, the primary comparisons of interest are between *Full Uncertain Prize* (Treatment 2) and *Asymmetric Full Uncertain Prize* (Treatment 4), as well as between *Partial Uncertain Prize* (Treatment 3) and *Asymmetric Partial Uncertain Prize* (Treatment 5). While we could have included a treatment with a residual claimant when the prize is known prior to maximum claims being awarded, we did not do so to balance the number of asymmetric treatments with the number of symmetric treatments, since subjects experienced either symmetric or asymmetric contests in an attempt to reduce subject confusion and experimenter demand effects.

Table 1. Details for Each Treatment

Treatment		R is Realized (Case)	Harvest Order Matters	Parameters	If R > T	Equilibrium Effort			Total Effort
Name	#					L_A	L_B	L_C	
Fixed Prize	1	Before Lobbying (Case 1)	No (Symmetric)	R = T = 120	NA	26.7	26.7	26.7	80.0
Full Uncertain Prize	2	After Lobbying Before Permits (Case 2)	No (Symmetric)	R~U[0,M] T = M = 240	NA	26.7	26.7	26.7	80.0
Partial Uncertain Prize	3	After Lobbying Before Permits (Case 2)	No (Symmetric)	R~U[0,M] M = 240 T = 120	R-T Forgone	20.0	20.0	20.0	60.0
Asymmetric Full Uncertain Prize	4	After Permits (Case 3)	Yes (Asymmetric)	R~U[0,M] T = M = 240	NA	30.0	30.0	0.0	60.0
Asymmetric Partial Uncertain Prize	5	After Permits (Case 3)	Yes (Asymmetric)	R~U[0,M] M = 240 T = 120	R-T Forgone	23.1	20.1	13.5	56.6
Residual Claimant	6	After Permits (Case 3)	Yes (Asymmetric)	R~U[0,M] M = 240 T = 120	R-T Awarded to C	23.1	20.1	13.5	56.6

Behavioral Hypotheses

Previous contest experiments have consistently reported subjects overbidding relative to the theoretical predictions (see Sheremeta (2019) for a review). Thus, we do not expect behavior to match the equilibrium predictions in Table 1. However, the equilibria also provide comparative static predictions regarding treatment and role effects, and it is those predictions that we seek to test. Here, we summarize these behavioral predictions.

The first two hypotheses examine behavior between players in a given treatment.

Symmetry Hypothesis: For Treatments 1, 2, and 3, a Player's role should not matter; thus, the effort exerted by A should equal the effort exerted by B, which in turn should equal the effort of C.

Asymmetry Hypothesis: For Treatments 4, 5, and 6, a Player's role should matter, such that the effort exerted by A should be greater than or equal to the effort exerted by B, which in turn should be greater than or equal to the effort exerted by C with strict inequalities holding as indicated in Table 1.

The next two hypotheses test whether features of the task influence behavior, even when those task features should not influence behavior.

Uncertainty Hypothesis: When harvest order does not matter, eliminating uncertainty while maintaining the expected prize does not impact effort (Treatments 1 and 2 yield the same behavior).

Residual Claimant Hypothesis: Making the third player a residual claimant does not impact the effort of any player (Treatments 5 and 6 yield the same behavior).

The next hypothesis examines the effect of setting a cap on the maximum amount of the resource that can be harvested.

Partial Prize Hypothesis: When the harvestable amount of the resource is restricted to less than the realized amount—regardless of whether or not harvest order matters—total effort decreases. That is, Treatment 2 leads to more total effort than Treatment 3, and Treatment 4 leads to more total effort than Treatments 5 and 6.

The final hypothesis is the main focus of the paper, and explores how the timing of assigning allowable harvests and the realization of the available resource impact behavior.

Timing Hypothesis: When players may not be able to claim their permitted share of the prize because permits are allocated prior to the available amount of the resource being realized, total effort decreases, regardless of whether the full resource is made available for harvest or not. Consequently, Treatment 2 leads to more effort than Treatment 4, and Treatment 3 leads to more effort than Treatments 5 and 6.

Experimental Procedures

In each laboratory session, there were at least 9 subjects, each of which competed in three of the possible contest treatments: the three symmetric contests (Treatments 1-3) or the three asymmetric contests (Treatments 4-6).[11] In each session, 20 contests were completed in each of the treatments, for a total of 60 rounds. A total of 24 sessions were conducted, 12 for the symmetric treatments and 12 for the asymmetric treatments. As a result, we observe 720 and 760 separate (although not independent) contests for asymmetric and symmetric treatments, respectively. The order of the three treatments within a session was varied across sessions to control for order effects. Specifically, we conducted two sessions in each of the 6 possible orders for each set. Before every contest, subjects were randomly and anonymously placed in groups of size three. Further, the A, B, and C roles were randomly assigned for each contest. Instructions for each treatment were provided immediately prior to the start of the twenty contests for that

[11] In one session of the symmetric treatment there were 15 subjects. Every other session included exactly 9 subjects. We find no substantive differences in the results with or without this larger session.

treatment.[12] Subjects were not informed of how many treatments they would complete during a session.

Subjects were undergraduates at the University of _______________ who were only allowed to participate in a single session and had no prior experience with any related studies. The experiments were conducted at the ____________________________ Laboratory at the university and each subject received $5 plus their salient earnings, which averaged $27.06, for the 120 minute session.[13] Earnings in the contest experiment were determined by selecting two rounds at random from each treatment (thus six rounds were used in determining payoffs). All amounts in the contest experiment were denoted in lab dollars, which the subjects were told in advance would be converted into US$ at the rate 16 Lab$ = US$ 1. To absorb potential losses, subjects were given an endowment of 60 Lab$. All contest experiments were preceded by a Holt-Laury multiple price list risk elicitation task with stakes four times the baseline level of Holt and Laury (2002). Earnings from the risk elicitation exercise were determined after the contest and added to earnings from the contest experiment and included in the average salient payment calculation.

Behavioral Results

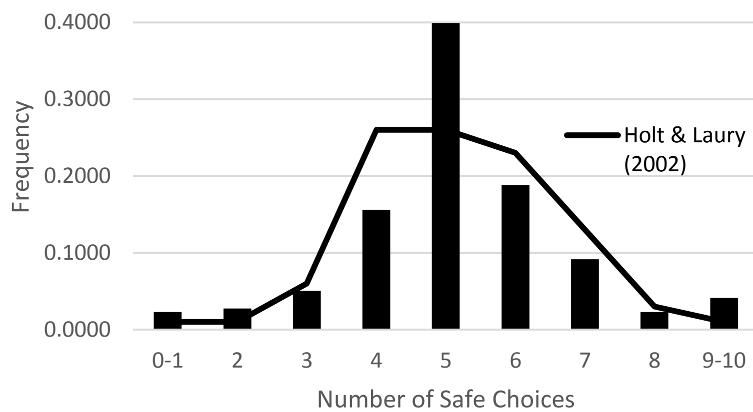
Before reporting the contest behavior, we examine the underlying assumption of risk neutrality. Figure 2 shows the distribution of the number of safe choices subjects made using the multiple price list procedure. For comparison, the baseline results of Holt and Laury (2002) are displayed in Figure 2 as well. The figure indicates that our subjects, like those in Holt and Laury (2002), tend to be slightly risk averse. We categorize the 22 subjects who made zero to three safe choice as risk seeking, the 34 subjects who made 4 safe choices as risk neutral, the 128 subjects who made five or six safe choices as moderately risk averse, and the 38 subjects who made more than six safe choices as extremely risk averse.[14]

[12] Copies of the instructions are included in Appendix 3.

[13] Experiments were programmed and implemented using oTree (Chen et al., 2016).

[14] Three subjects did not complete the risk elicitation task. Holt and Laury (2002) report that increased stakes leads to greater risk aversion, consistent with the difference between our subjects and their baseline measure.

Figure 2. Number of Safe Choices in Risk Elicitation



We now turn to contest behavior. Table 2 summarizes observed lobbying efforts. The first thing that is apparent from the table is that subjects overbid in comparison to the theoretical predictions: the average investment significantly exceeds the predicted amount in 17 of the 18 combinations of role and treatment. Such overbidding in contests is common in laboratory experiments. In fact, our *Fixed Prize* treatment is directly comparable to previous contest experiments since the prize is known with certainty to the bidders prior to bidding. On average, subjects bid 36 in *Fixed Prize*, or 35% above the equilibrium level. For comparison, Lim, Matros, and Turocy (2014) report that bids were 32% and 60% above the predicted level with N=2 and N=4 bidders respectively. Sheremeta (2011) reported overbidding of 33% with N=2 bidders. This suggests that the subject pool and graphical interface used in our experiment are not impacting observed behavior.

Using a Kolmogorov-Smirnov test, we find no difference in the distribution of risk attitudes across our symmetric and asymmetric groups (D= 0.0548, p = 0.997).

Table 2. Equilibrium Predictions and Observed Behavior

Treatment		Equilibrium Predictions				Observed Behavior			
Name	#	L_A	L_B	L_C	Total	L_A	L_B	L_C	Total
Fixed Prize	1	26.7	26.7	26.7	80.0	35.5*** (1.68)	37.4*** (1.73)	35.1*** (1.68)	108.0
Full Uncertain Prize	2	26.7	26.7	26.7	80.0	31.7*** (1.37)	32.4*** (1.10)	31.7*** (1.17)	95.8
Partial Uncertain Prize	3	20.0	20.0	20.0	60.0	27.4*** (1.40)	28.6*** (1.74)	28.1*** (1.33)	84.1
Asymmetric Full Uncertain Prize	4	30.0	30.0	0.0	60.0	37.8*** (1.78)	27.1** (1.19)	20.4*** (1.06)	85.3
Asymmetric Partial Uncertain Prize	5	23.1	20.1	13.5	56.6	34.2*** (1.65)	25.8*** (1.27)	18.8** (1.94)	78.8
Residual Claimant	6	23.1	20.1	13.5	56.6	33.1*** (1.57)	25.2*** (1.33)	21.5*** (1.71)	79.8

*p<0.1; **p<0.05; ***p<0.01 denote an observed mean that is statistically different than the predicted mean. The tests were conducted by regressing the observed behavior on a constant, allowing for standard errors clustered at the session level, followed by a Wald test of whether the observed mean is statistically different than the theoretical prediction. Standard errors of regressions are given in parentheses. Differences remain significant if subject fixed effects are included, except for player B in Treatment 4.

Next, we test each of the six behavioral hypotheses. The *Symmetry Hypothesis* holds that lobbying effort does not depend on role in Treatments 1, 2 or 3. Table 3 reports regression results to test this hypothesis. In these specifications, the *Constant* term captures the bid of Player A, while *Second* captures the difference between bids by Player A and Player B; thus, Player B's bid is given by *Constant* + *Second*.[15] *Third* captures the difference between the bid of Player C and Player A, and thus, Player C's bid is given by *Constant* + *Third*. Comparison of Player B and C's behavior is captured by the Wald test in Table 3, which tests for player differences, i.e. *Second - Third =0*. Formally, the *Symmetry Hypothesis* is that *Second = Third* = 0 for each of the first three treatments, and the related test statistic is also included in Table 3. The regressions include subject fixed effects and standard errors clustered at the session level; results are robust with and without clustered standard errors, as are estimates using a mixed random effects model.[16]

[15] The fixed effects are normalized to zero, so the intercept is the average bid of Player A.

[16] Out of concern that the number of sessions is too small for cluster-robust standard errors, we use the STATA user-written command boottest, a post estimation command (Roodman et al., 2019) that uses wild cluster bootstrapping to derive a small-cluster distribution of the Wald tests under the null hypothesis of our parameter values (Cameron et al., 2008). For all treatments and cases that we consider, we do not find a significant variation from our reported p-values.

As shown in Table 3, there are no significant differences between players in Treatments 1-3, with one exception. In Treatment 3, Player C outbids Players A by a statistically significant, although economically small, amount: a difference of 1.2. Overall, results support the *Symmetry Hypothesis*. Similar conclusions are drawn using non-parametric signed rank sum tests.[17] Finally, we note that risk aversion would lead to lower effort in Treatments 2 and 3, but would not alter the *Symmetry Hypothesis.*[18]

Table 3. Symmetry and Asymmetry Hypothesis Tests: Lobbying Effort by Player and Treatment

	(1) Fixed Prize (Treatment 1)	(2) Full Uncertain Prize (Treatment 2)	(3) Partial Uncertain Prize (Treatment 3)	(4) Asymmetric Full Uncertain Prize (Treatment 4)	(5) Asymmetric Partial Uncertain Prize (Treatment 5)	(6) Residual Claimant (Treatment 6)
Second	1.016	-0.220	0.241	-10.794***	-8.267***	-6.701***
	(0.63)	(0.62)	(0.62)	(0.70)	(1.00)	(1.47)
Third	0.010	-0.723	1.206**	-18.499***	-14.838***	-11.573***
	(0.52)	(0.48)	(0.44)	(1.44)	(1.49)	(1.98)
Constant	35.663***	32.228***	27.518***	38.230***	33.945***	32.708***
	(0.29)	(0.30)	(0.33)	(0.66)	(0.79)	(1.10)
Wald Test Ho: Second - Third = 0	1.81 (0.2059)	0.59 (0.4569)	5.94** (0.0330)	50.66*** (0.0000)	47.70*** (0.0000)	19.02*** (0.0011)
Wald Test Ho: Second = Third = 0	1.34 (0.3011)	1.14 (0.3558)	7.55*** (0.0086)	122.89*** (0.0000)	49.67*** (0.0000)	17.21*** (0.0004)
N	2280	2280	2280	2160	2160	2160

*p<0.1; **p<0.05; ***p<0.01. Includes subject fixed effects. Robust standard errors are clustered at the session-level.

The *Asymmetry Hypothesis* holds that in Treatments 4, 5, and 6, those who claim their prizes later should not bid more than those who claim their prizes earlier. To test this hypothesis, we rely upon regression analysis similar to that done for the Symmetry Hypotheses. However, the prediction is now that Second < 0 and Third < 0 (except for Treatment 4, where the prediction is that Second = 0). These results are presented in Table 3 as well. As indicated, Players B and C

[17] For Treatment 1, the p-values for comparing Player A with Player B, Player A with Player C, and Player B with Player C are 0.0340, 0.3898, and 0.0278, respectively. For Treatment 2, the p-values for comparing Player A with Player B, Player A with Player C, and Player B with Player C are 0.3472, 0.8103, and 0.1164, respectively. For Treatment 3, the p-values for comparing Player A with Player B, Player A with Player C, and Player B with Player C are 0.4778, 0.5823, and 0.6965, respectively. Thus, on net, the parametric and non-parametric analysis find similar levels of support for the *Symmetry Hypothesis*.

[18] Here and elsewhere, when discussing the impact of risk aversion on predicted behavior, it is based on the numerical solutions in Appendix 1 under the assumption that each player has the same degree of constant relative risk aversion.

bid significantly less than Player A in each treatment. In addition, Player C always bids significantly less than Player B in each asymmetric treatment. The same conclusions are drawn when relying on a signed rank sum test.[19] These results generally match the comparative statics of the model and support the *Asymmetry Hypothesis*: in every case where order matters, those whose claims are filled later bid less than those whose claims are filled earlier. The one exception is that Player B is expected to invest as much as Player A in Treatment 4, but actually invests less. A difference in investment between Players A and B in Treatment 4 is consistent with mild to moderate risk aversion, although as shown in Appendix 1, the magnitude of the investment difference is predicted to be much smaller than the gap shown in Table 2.

To test the *Uncertainty Hypothesis*, which predicts that behavior in Treatments 1 and 2 is the same, we again rely upon regression analysis allowing for subject fixed effects and errors clustered at the session-level. Because the *Symmetry Hypothesis* has been shown to hold, we combine data across roles to test if behavior changes when the prize is uncertain (but each player will receive its permitted amount). The results, shown in column 1 of Table 4, indicate that this type of uncertainty reduces lobbying effort. Effort in the Fixed Prize Treatment (T1) is significantly greater than in the Full Prize Treatment (T2). This result is also supported by a signed rank sum test (p-value = 0.0340). As shown in Appendix 1, the reduction in investment with an uncertain prize is consistent with risk aversion.

To further investigate the role that risk aversion plays in the observed behavior, we report lobbying effort by risk categorizations in Table 4. For all risk categories, the lobbying effort is at least nominally greater when the prize amount is known (T1). Statistically and economically significant differences are observed for the risk neutral and extremely risk averse subjects.[20]

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[19] p-values for comparing players in Treatment 4 are all 0.0022, as are all pairwise player comparisons in Treatment 5. For Treatment 6, the p-values for comparing Player A with Player B, Player A with Player C, and Player B with Player C are 0.0037, 0.0022, and 0.0076, respectively.

[20] The wild bootstrapping technique increases the p–value associated with the risk neutral results from p = 0.063 to p = 0.0841 for the risk-neutral group and from p = 0.039 to p = 0.0841 for the extremely risk averse.

Table 4. Uncertainty Hypothesis Test: Lobbying Effort for Treatment 1 and Treatment 2

	All Players	Risk Seeking Players	Risk Neutral Players	Moderate Risk Averse Players	Extreme Risk Averse Players
Fixed Prize (T1)	4.091*	1.610	5.885*	3.296	7.266**
	(1.96)	(2.95)	(2.73)	(2.66)	(2.76)
Constant	31.914***	34.340***	31.971***	32.071***	29.641***
	(0.98)	(1.48)	(1.37)	(1.33)	(1.38)
N	4,560	400	680	2,840	640

*p<0.1; **p<0.05; ***p<0.01. Includes subject fixed effects. Robust standard errors are clustered at the session-level.

We test the *Residual Claimant Hypothesis*—i.e., that behavior is the same in treatments 5 and 6—using specifications (1) – (4) in Table 5. Because behavior depends on role in these treatments, we test the treatment effect overall (specification 1) and separately for each position (specifications 2-4). Regression results indicate that Players A, B and C do not change their behavior in response to Player C being a residual claimant. Player C, who is the residual claimant in Treatment 6, allocates slightly more effort, but the difference is not statistically significant (p=0.183). Non-parametric analysis yields the same conclusions.[21] Interestingly, even under mild risk aversion, Players A and B should not substantially change their behavior between Treatments 5 and 6, but Player C should invest less under Treatment 6 than Treatment 5, and thus the total lobbying effort should also be lower in Treatment 6 if subjects are risk averse. This is nominally the opposite of the observed pattern. As shown in more detail in Appendix 2, Table A2.1, the extremely risk averse subjects are responsible for the increase in Player C's effort.

Table 5. Residual Claimant Hypothesis Test: Lobbying Effort Between Asymmetric Treatments

	(1) All Players	(2) Player A	(3) Player B	(4) Player C
Residual Claimant (T6)	0.373	-1.187	0.020	2.375
	(0.99)	(1.45)	(0.67)	(1.67)
Constant	26.244***	34.217***	25.491***	18.979***
	(0.50)	(0.72)	(0.34)	(0.83)
N	4320	1440	1440	1440

*p<0.1; **p<0.05; ***p<0.01. Includes subject fixed effects. Robust standard errors are clustered at the session-level.

[21] The p-values for the signed rank sum tests comparing total lobbying, Player A lobbying, Player B lobbying, and Player C lobbying between Treatments 5 and 6 are 0.5287, 0.2713, 0.4777, and 0.1585, respectively.

The *Partial Prize Hypothesis* states that the total amount invested is reduced when there is a cap on the amount of the resource that can be claimed. This pattern is intuitive because the distribution of the available resource with the cap is first-order stochastically dominated by the distribution without the cap, and thus, it is a complex variation of the incentive effect discussed by Sheremeta (2019). To test the *Partial Prize Hypothesis*, we compare lobbying investment in Treatment 2 and 3 (top panel in Table 6) as well as Treatments 4 and 5 (bottom panel in Table 6) as these are the only treatment pairs that vary only by the presence of a cap. Once again, we rely on regression analysis with standard errors clustered at the session level. In specification (1) of Table 6, we use total group effort, which is not subject specific, so we include session fixed effects. In specifications (2)-(4), we regress subject-level effort for all player positions combined and separately for individual player positions. For both pairs of treatments, the unrestricted case is captured by the constant term while the effect of placing a cap on the amount of the resource that can be harvested is captured by the variable *Cap*.

The evidence on the *Partial Prize Hypothesis* is somewhat mixed, but on the whole supportive of it. For specifications (1) and (2), the prediction is that total effort will decrease with the cap (*Cap* < 0), which is consistent with both sets of results shown in Table 6 and supportive of the *Partial Prize Hypothesis*. For the symmetric case, all players are predicted to decrease their effort uniformly; in contrast, only Players A and B are predicted to reduce effort for the asymmetric case, while Player C is predicted to increase effort. The reduction in effort is statistically significant for Players A and B in the symmetric case, but not Player C, although the effect is similar in size for all three players as predicted. For the asymmetric case, the impact of the cap is significant for Player A as predicted, but not for Player B or C. Again, the non-parametric analysis is largely consistent with the regression results.[22]

[22] Using signed rank sum tests, the total lobbying differs between Treatments 2 and 3 (p-value = 0.034) and at least marginally for Treatments 4 and 5 (p-value = 0.0500). For Player A, the impact of a cap is marginally significant for the symmetric treatments (p-value = 0.0836) and the asymmetric case (p-value = 0.0500). For Player B, the impact of a cap is significant for the symmetric treatments (p-value = 0.0278 and marginally significant for the asymmetric case (p-value = 0.0989). For Player C, the impact of a cap is significant for the symmetric treatments (p-value = 0.0414) and not in the asymmetric case (p-value = 0.4354).

Table 6. Partial Prize Hypothesis Test: Lobbying Effort in Full versus Partial Prize Treatments

		(1) Group Total	(2) Individual	(3) Player A	(4) Player B	(5) Player C
Symmetric	Cap	-11.752**	-3.914**	-5.240**	-4.215**	-2.845
		(4.57)	(1.53)	(1.82)	(1.47)	(1.79)
	Constant	84.500***	31.914***	32.165***	32.564***	31.293***
		(2.30)	(0.76)	(0.91)	(0.74)	(0.89)
	N	1520	4560	1520	1520	1520
Asymmetric	Cap	-6.741**	-2.222*	-4.205**	-1.666	-0.487
		(3.12)	(1.02)	(1.44)	(0.96)	(1.77)
	Constant	85.375***	28.465***	38.102***	27.277***	19.863***
		(1.55)	(0.51)	(0.72)	(0.48)	(0.88)
	N	1440	4320	1440	1440	1440
Fixed Effects		*Session*	*Individual*	*Individual*	*Individual*	*Individual*

*p<0.1; **p<0.05; ***p<0.01. Equations (2)-(5) include subject fixed effects. Robust standard errors are clustered at the session-level.

While some of the observed effects of a cap are consistent with risk aversion, that is not a full explanation. With risk aversion, a cap should still lead to less total lobbying when the players are symmetric; however, greater risk aversion reduces the predicted impact of the cap such that if players are highly risk averse, there would be little difference between Treatments 2 and 3 (Figure A1.3). Thus, the smaller (in absolute value) coefficients on Cap, relative to those predicted, could be due to risk aversion. Related regression results by risk category in Appendix 2 are consistent with predicted behavior for extremely risk averse subjects.

However, for the case when players are asymmetric, Treatment 5 is predicted to have more total lobbying than Treatment 4 with moderate risk aversion, meaning the effect of the Cap is reversed in comparison to risk neutral players. Thus, the coefficient on Cap in (1) for the lower panel of Table 6 is not consistent with moderate or strong risk aversion. For player A, the predicted coefficient on Cap is increasing in risk aversion, becoming positive with strong risk aversion so the coefficient observed in (3) for the lower panel of Table 6 is consistent with moderate risk aversion. For Player B, increased risk leads to a larger, but still negative coefficient on *Cap*, while increased risk aversion predicts a smaller but still positive coefficient on *Cap* for

Player C. Thus, the coefficients on Cap in (4) and (5) for the lower panel of Table 6 are consistent with extreme risk aversion.[23]

Finally, the *Timing Hypothesis* posits that when allocations are awarded prior to the realization of the amount of the resource that is actually available, the total amount of lobbying decreases, despite the heterogeneous responses of the individual players—Player A is predicted to increase effort, Player B is predicted to increase (no cap) or not change (with cap) their effort, and Player C is predicted to decrease their effort. The regression analysis associated with testing this hypothesis is shown in Table 7, with the top panel presenting results with no cap (Treatments 2 and 4) and the bottom panel presenting the results with the existence of a cap on the available resource (Treatments 3 and 5). Once again, we rely upon regression analysis, with standard errors clustered at the session level, but do not include subject fixed effects, since participants in a session did not compete under both Treatments 2 and 4 (or Treatments 3 and 5). The constant term captures total lobbying when the realization occurs before allocations are determined, while the variable *Asymmetric* captures the effect of the realization occurring after allocations are awarded relative to the symmetric prize treatment.

In Table 7, *Asymmetric* is negative and significant for total effort (specification 1, top panel) for the full uncertain prize case (i.e., No Cap), but is not statistically significant in the partial uncertain prize (specification 1, lower panel). This is largely consistent with the *Timing Hypothesis* since the decrease in total effort is predicted to be large with a full uncertain prize and economically small for the partial uncertain prize. The player-specific effects are also largely consistent with the theoretical predictions (specifications 3-5): Player A increases effort in both treatments; Player B does not change their effort under the partial prize; and Player C decreases effort in both cases. The only inconsistency with the predictions is that Player B appears to decrease their effort under the full prize, despite being predicted to increase their effort. Non-parametric analysis also supports these conclusions.[24]

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[23] Related results by risk category are provided in Appendix 2 Table A2b. Results are somewhat consistent with predictions for Players A and B but not for Player C.

[24] Because the effect of timing is measured between subjects, we rely upon rank sum test rather than singed rank sum tests. Without a cap total lobbying differs based on timing (Treatment 2 versus Treatment 4) as the p-value = 0.0496, but with a cap the difference in total lobbying based on timing (Treatment 3 versus Treatment 5) is not significant as the p-value = 0.4776. For Player A, the p-values comparing Treatments 2 and 4 and Treatments 3

The observed behavior of Player B is consistent with moderate risk aversion as this would lead to greater lobbying in Treatment 4 than Treatment 2 and only a small difference in lobbying between Treatments 3 and 5. However, moderate risk aversion should cause a similar, albeit smaller, shift in Player A's behavior in the absence of a cap, and it does not. With a cap, moderate risk aversion would still imply Player A should lobby more in Treatment 5 and Treatment 3, consistent with (3) in the lower panel of Table 7. With regards to Player C, risk aversion would not substantially change the comparative static predictions with regards to timing.

Table 7. Timing Hypothesis Test: Lobbying Effort in Asymmetric versus Symmetric Prize Treatments

		(1)	(2)	(3)	(4)	(5)
		Group Total	Individual	Player A	Player B	Player C
No Cap	Asymmetric	-10.515**	-3.449**	5.805***	-4.668***	-11.878***
		(4.78)	(1.59)	(2.19)	(1.57)	(1.53)
	Constant	95.815***	31.914***	32.345***	32.098***	31.618***
		(3.41)	(1.11)	(1.29)	(0.98)	(1.18)
	N	1480	4440	1480	1480	1480
Cap	Asymmetric	-5.872	-1.757	6.837***	-1.988	-9.264***
		(6.03)	(1.97)	(2.12)	(2.00)	(2.21)
	Constant	84.282***	28.000***	27.241***	27.785***	28.379***
		(4.28)	(1.37)	(1.43)	(1.54)	(1.29)
	N	1480	4440	1480	1480	1480

*p<0.1; **p<0.05; ***p<0.01. Robust standard errors are clustered at the session-level.

Discussion

Many natural resource allocation problems, such as the right to harvest fish or pump water from a river, can be viewed as contests where the prize is uncertain. In these situations, the contestants are awarded shares of the resource which are claimed in a sequential fashion. Upstream farmers can siphon water before it reaches downstream farmers. Ocean-based commercial fishers can harvest salmon before river-based sport fishers. If the uncertainty regarding the amount of the available resource is not resolved prior to claims being made, the

and 5 are 0.0068 and 0.0094, respectively. For Player B, the p-values comparing Treatments 2 and 4 and Treatments 3 and 5 are 0.0083 and 0.2913, respectively. For Player C, the p-values comparing Treatments 2 and 4 and Treatments 3 and 5 are <0.0001 and 0.0036, respectively.

sequential nature of the allocation process creates an asymmetry among otherwise symmetric players. A similar phenomenon can occur in other settings, such as bankruptcy claims where some creditors are given priority.

This paper models sequential-award contests with an uncertain prize and tests the predictions using controlled laboratory experiments. Specially, we develop and test six behavioral hypotheses. The main finding is that when the amount of the available prize is not known at the time shares of the resource are claimed, players invest less in competitive effort, relative to when the available price is known before sequential claims are made (support for the *Timing Hypothesis*). We also find evidence that when uncertainty is resolved before prize shares are claimed, the sequential aspect of the allocation does not impact behavior, which is consistent with our theoretical predictions (support for the *Symmetry Hypothesis*). Furthermore, when uncertainty is not resolved prior to prizes being claimed, then players who are further back in the queue invest less, which is also consistent with our theoretical predictions (support for the *Asymmetry Hypothesis*). We also find some evidence that behavior responds to features of the contest that are not predicted to matter in that people bid more when prize uncertainty is resolved prior to investment (evidence against the *Uncertainty Hypothesis,* but consistent with risk aversion). Finally, we find evidence that players invest less when the expected value of an uncertain prize decreases (support for the *Partial Prize Hypothesis*) and we find that allowing for a residual claimant does not impact behavior (evidence for the *Residual Claimant Hypothesis*).

Although our framework differs from the common pool resource literature, there are some useful comparisons. When the size of the resource is known, the strategic interaction in our symmetric case yields a different prediction than related common pool/irrigation literature, but our asymmetric treatments yield similar predictions. Ostrom and Gardner (1993) predict that in a sequential game Player 1 invests more in the resource relative to Player 2 and Player 1 receives more water; Janssen et al., (2011b) provide supporting experimental evidence. Similarly, in our asymmetric treatments, we find evidence that a player's role matters and investment is greater for players first in the sequence (i.e. Asymmetry Hypothesis). However, in our symmetric treatments, we find no significant differences in investment across player types (i.e. Symmetry Hypothesis).

While there is a large literature on behavior in contests, there has been relatively little attention paid to the effects of uncertainty regarding the prize or the chance that the contestants will receive their awarded share, despite the existence of such possibilities in many settings. Our *Fixed Prize* treatment is comparable to previous proportional prize contest experiments and the behavior that we observe is typical: people over invest relative to the equilibrium level, and as a result, much of the expected surplus is dissipated. Our results are also consistent with previous work showing an incentive effect that leads people to invest less when the prize is reduced (the *Partial Prize Hypothesis*). But our work also offers new insights. For example, increasing uncertainty about the prize while holding the expected value constant leads to lower investment, and thus reduced rent dissipation, suggesting that contest designers who are motivated by contestant welfare concerns rather than investment maximization may want to add uncertainty. This finding is not inconsistent with conclusions drawn by previous experiments (e.g. Chowdhury et al., 2014, Cason, et al., 2020, Masiliūnas 2020) that increased uncertainty leads to overbidding. In our setting, uncertainty refers to exogenous variation in the size of the prize, whereas other studies have tended to be concerned with the distinction between proportional and winner-take-all contests, in which uncertainty arises from the chance of receiving the prize.

Our work also suggests that dissipation can be further reduced by awarding shares sequentially. This works because the sequential process discourages the last claimant from investing by more than it encourages the first claimant to invest. Of course, this asymmetric process introduces inequality into the distributions of investment and payoffs. We hope this paper will spur investigation into other features of practical significance for contest implementation.

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Appendix 1. Theoretical Derivations and Numerical Estimations

Numerical Solutions for Equilibrium Behavior in Asymmetric Cases under Risk Neutrality

Figure A1 provides the numerical solution for best response surfaces for each player in Treatments 5 and 6. Figure A2 plots the Nash equilibrium lobbying effort for each player as a function of the threshold (T). For Treatment 4, the threshold is T=240 and the equilibrium predictions are on the right edge of Figure A2. For Treatments 5 and 6, T = 120 and the equilibrium lobbying efforts are shown on the left edge of Figure A2 and are the ones that for which each player is best responding to the others given the surfaces in Figure A1.

Figure A1.1: Best Response Surfaces for Players A, B, and C for Treatments 5 and 6

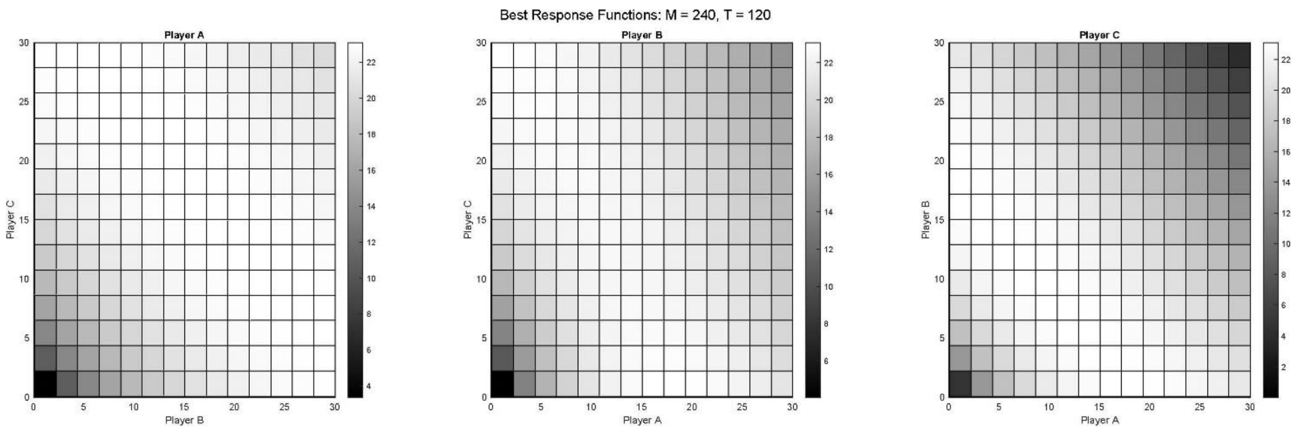
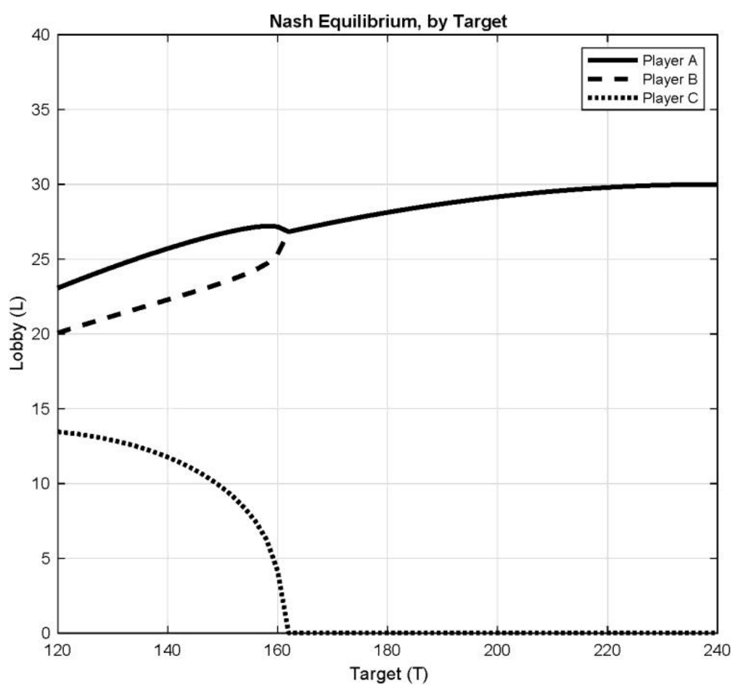


Figure A1.2: Nash Equilibrium Lobbying for Treatments 4, 5 and 6, as a Function of Target (*T*).



Derivations for a General Version of the Contest Allowing for Risk Aversion

In this subsection, we explore a more general formulation of the contest that allows us to explore the implications of introducing risk aversion into our theoretical model.

Let x_i denote player *i*'s payoff and consider the general utility function $u(x_i)$ with $u'(x_i) > 0$ and $u''(x_i) \leq 0$. The payoff function takes the form

$$x_i = E_i + H_i - L_i,$$

where T is the target set by the government, H_i is the value of player *i*'s harvest, E_i is player *i*'s endowment, and L_i is player *i*'s lobbying effort.

Case 1: R Known Prior to Lobbying and Permit Awards

In the first case, the size of the resource *R* is known and the government is assumed to be willing to allocate the entire resource (i.e., $T = R$). Thus, the value of player *i*'s harvest is equal to a share of the target:

$$H_i = s_i T,$$

where $s_i = L_i / \sum_{j \in I} L_j$ is player *i*'s share of the realized resource. The first-order condition for player *i* is thus:

$$\frac{\partial u(x_i)}{\partial L_i} = u'(x_i) x_i' = 0,$$

where

$$x_i' = s_i' T - 1 = \frac{\sum_{j \neq i} L_j}{\left(\sum_{j \in I} L_j\right)^2} T - 1.$$

This implies

$$u'(x_i)(s_i' T - 1) = 0.$$

Note that for $x_i > 0$, the unique best response function is determined by $s_i'T = 1$. Thus, the symmetric Nash equilibrium lobbying effort is $L_i^* = 2R/9$ and is independent of risk preferences, as expected.

If the government set a target $T = \bar{T} < R$, then there would be some resource left over after the permitted harvests were collected. If player C is a residual claimant, then player C's payoff would become $x_C = E_C + s_C\bar{T} - L_C + R - \bar{T}$. The first order conditions would be identical to those above, and thus, the equilibrium lobbying effort would be $L_i^* = 2\bar{T}/9$ and each player is guaranteed to receive their permitted harvest.

Case 2: R Known After Lobbying but Before Permit Awards

In the second case, the problem is again a symmetric Tullock contest, but with an uncertain prize. Since the permits are awarded after *R* is realized, the sum of permits will be equal to the target *T*; thus, the value of player *i*'s harvest is equal to a share of the target, as in Case 1. Assuming the government will allocate the entire realized resource (i.e., $T = R$), player *i* would maximize expected utility of the form:

$$E[u(x_i)] = \int_0^M f(T)u(x_i(T))dT,$$

where $f(T) = 1/M$ denotes the uniform[*0,M*] probability density function for the target T. This leads to the first order condition of

$$\frac{\partial E[u(x_i)]}{\partial L_i} = \int_0^M f(T)u'\big(x_i(T)\big)x_i'(T)dT = 0.$$

There is no general closed-form representation for the symmetric Nash equilibrium lobbying effort for this case; however, as we show below, a closed-form solution does exist when players are risk neutral.

If the government instead sets $T = \bar{T} < M$, then expected utility has the form:

$$E[u(x_i)] = \int_0^{\bar{T}} f(T)u(x_i(T))dT + \int_{\bar{T}}^{M} f(r)u\big(x_i(\bar{T})\big)dr$$
$$= \int_0^{\bar{T}} f(T)u\big(x_i(T)\big)dT + \frac{M-\bar{T}}{M}u\big(x_i(\bar{T})\big).$$

This leads to the first order condition of:

$$\frac{\partial E[u(x_i)]}{\partial L_i} = \int_0^{\bar{T}} f(T)u'(x_i(T))x_i'(T)dT + \frac{M-\bar{T}}{M}u'\big(x_i(\bar{T})\big)x_i'(\bar{T}) = 0.$$

As before, a closed-form solution for the symmetric Nash equilibrium lobbying effort exists when players are risk neutral. As in case 1, there may be some of the resource left over. If player C were a residual claimant on this portion of the resource, it would become $x_C = E_C + s_C\bar{T} - L_C + R - \bar{T}$ if $R > \bar{T}$. If player C is risk neutral, so that $u'(x_i)$ is independent of x_i, then this does not change the equilibrium outcome. However, if player C is risk averse so that that $u'(x_i)$ decreases with x_i, then player C's expected utility has the form

$$E[u(x_C)] = \int_0^{\bar{T}} f(T)u(x_C(T))dT + \int_{\bar{T}}^{M} f(r)u\big(x_C(\bar{T},r)\big)dr$$

with a corresponding first order condition of

$$\frac{\partial E[u(x_C)]}{\partial L_C} = \int_0^{\bar{T}} f(T)u'(x_C(T))x_C'(T)dT + \int_{\bar{T}}^{M} f(r)u'\big(x_C(\bar{T},r)\big)x_i'(\bar{T})dr = 0.$$

Thus, having a residual claimant will change the equilibrium outcome. We explore this in more detail below.

Case 3: R Known After Permit Awards

In this case, permits are awarded based on the target *T*; however, because *T* is set before *R* is realized, *T* could exceed *R*. Thus, it is possible that not every player is able to harvest the permitted amount. For example, if $R < s_A T$, then player A will be rewarded the entire resource and players B and C will be rewarded nothing. For a given lobbying effort and target, the payoff functions for the three players will be:

$$x_A = \begin{cases} E_A + R - L_A & \text{if } R < s_A T \\ E_A + s_A T - L_A & \text{if } s_A T \leq R; \end{cases}$$

$$x_B = \begin{cases} E_B - L_B & \text{if } R < s_A T \\ E_B + R - s_A T - L_B & \text{if } s_A T \leq R < s_A T + s_B T \\ E_B + s_B T - L_B & \text{if } s_A T + s_B T \leq R; \end{cases}$$

$$x_C = \begin{cases} E_C - L_C & \text{if } R < s_A T + s_B T \\ E_C + R - s_A T - s_B T - L_C & \text{if } s_A T + s_B T \leq R < T \\ E_C + s_C T - L_C & \text{if } T \leq R. \end{cases}$$

The expected utilities for the three players are thus:

$$E[u(x_A)] = \int_0^{s_A T} f(r) u(E_A + r - L_A) dr + \int_{s_A T}^{M} f(r) u(E_A + s_A T - L_A) dr$$

$$= \frac{1}{M} \int_0^{s_A T} u(E_A + r - L_A) dr + \frac{M - s_A T}{M} u(E_A + s_A T - L_A);$$

$$E[u(x_B)] = \int_0^{s_A T} f(r) u(E_B - L_B) dr + \int_{s_A T}^{s_A T + s_B T} f(r) u(E_B + r - s_A T - L_B) dr$$

$$+ \int_{s_A T + s_B T}^{M} f(r) u(E_B + s_B T - L_B) dr$$

$$= \frac{s_A T}{M} u(E_B - L_B) + \frac{1}{M} \int_{s_A T}^{s_A T + s_B T} u(E_B + r - s_A T - L_B) dr$$

$$+ \frac{M - s_A T - s_B T}{M} u(E_B + s_B T - L_B);$$

$$E[u(x_C)] = \int_0^{s_A T + s_B T} f(r) u(E_C - L_C) dr + \int_{s_A T + s_B T}^{T} f(r) u(E_C + r - s_A T - s_B T - L_C) dr$$

$$+ \int_T^M f(r) u(E_C + s_C T - L_C) dr$$

$$= \frac{s_A T + s_B T}{M} u(E_C - L_C) + \frac{1}{M} \int_{s_A T + s_B T}^{T} u(E_C + r - s_A T - s_B T - L_C) dr$$

$$+ \frac{M - T}{M} u(E_C + s_C T - L_C).$$

This leads to the following first order conditions:

$$\frac{\partial E[u(x_A)]}{\partial L_A} = -\int_0^{s_A T} u'(E_A + r - L_A)dr + (M - s_A T)u'(E_A + s_A T - L_A)(s_A' T - 1) = 0;$$

$$\frac{\partial E[u(x_B)]}{\partial L_B} = -s_A T u'(E_B - L_B) - \int_{s_A T}^{s_A T + s_B T} u'(E_B + r - s_A T - L_B)(s_A' T + 1)dr + (M - s_A T - s_B T)u'(E_B + s_B T - L_B)(s_B' T - 1) = 0;$$

$$\frac{\partial E[u(x_C)]}{\partial L_C} = -(s_A + s_B)T u'(E_C - L_C) - \int_{s_A T + s_B T}^{T} u'(E_C + r - s_A T - s_B T - L_C)(s_A' T + s_B' T + 1)dr + (M - T)u'(E_C + s_C T - L_C)(s_C' T - 1) = 0.$$

Notice that if player C is a residual claimant, then player C's payoff would become $x_C = E_C + s_C T - L_C + R - T$ if $R > T$. As in Case 2, this does not change the equilibrium outcome if player C is risk neutral. However, if player C is risk averse, so that that $u'(x_i)$ decreases with x_i, then player C's expected utility has the form

$$E[u(x_C)] = \frac{s_A T + s_B T}{M} u(E_C - L_C) + \frac{1}{M}\int_{s_A T + s_B T}^{T} u(E_C + r - s_A T - s_B T - L_C)dr + \frac{1}{M}\int_T^M u(E_C + s_C T - L_C + r - T)dr$$

with a corresponding first order condition of

$$\frac{\partial E[u(x_C)]}{\partial L_C} = -(s_A + s_B)T u'(E_C - L_C) - \int_{s_A T + s_B T}^{T} u'(E_C + r - s_A T - s_B T - L_C)(s_A' T + s_B' T + 1)dr + \frac{1}{M}\int_T^M u'(E_C + s_C T - L_C + r - T)(s_C' T - 1)dr = 0.$$

Thus, having a residual claimant will change the equilibrium outcome. We explore this in more detail below.

Equilibrium Effort with Homogenous Constant Relative Risk Aversion (CRRA) Utility Function

In this subsection, we consider the special case in which the preferences of all players can be captured by the CRRA utility function:

$$u(x_i) = \begin{cases} \dfrac{1}{1-\theta} {x_i}^{1-\theta} & \text{if } \theta > 0, \theta \neq 1 \\ \ln(x_i) & \text{if } \theta = 1, \end{cases}$$

where the parameter θ denotes the common constant relative risk aversion, with higher levels of θ representing more risk aversion. The special case of $\theta = 0$ represents a risk-neutral player, which we consider in the main body of the paper. It is useful to note the following first derivative of the utility function:

$$u'(x_i) = \begin{cases} {x_i}^{-\theta} & \text{if } \theta > 0, \theta \neq 1 \\ 1/x_i & \text{if } \theta = 1. \end{cases}$$

Case 1: R Known Prior to Lobbying and Permit Awards

As shown above, for $x_i > 0$, the unique best response function is determined by $s_i'T = 1$. Thus, the symmetric Nash equilibrium lobbying effort is $L_i^* = 2R/9$ and is independent of risk preferences.

Case 2: R Known After Lobbying but Before Permit Awards

As discussed above, there is no closed-form solution for the symmetric Nash equilibrium if players are risk averse. We solve for the Nash equilibrium lobbying efforts numerically for different values of the risk aversion parameter θ; the results are presented in Figures A3 and A4.

For the risk-neutral case (i.e., $\theta = 0$), which is considered in the main body of the paper, the utility is linear in the payoff; thus, the first derivative of utility (with respect to the payoff) is equal to one. If the government will allocate the entire realized resource (i.e., $T = R$), then the first order conditions become

$$\frac{\partial E[u(x_i)]}{\partial L_i} = \int_0^M f(T) x_i'(T) dT$$
$$= s_i' E(T) - 1$$
$$= \frac{\sum_{j \neq i} L_j}{\left(\sum_{j \in I} L_j\right)^2} \frac{M}{2} - 1$$
$$= 0.$$

This leads to a symmetric Nash equilibrium of $L_i^* = 2R/9$, as in Case 1.

If the government instead sets $T = \bar{T} < M$, then the first order conditions become

$$\frac{\partial E[u(x_i)]}{\partial L_i} = \int_0^{\bar{T}} f(T) x_i'(T) dT + \frac{M - \bar{T}}{M} x_i'(\bar{T})$$
$$= \frac{1}{M} \int_0^{\bar{T}} (s_i' T - 1) dT + \frac{M - \bar{T}}{M} (s_i' \bar{T} - 1)$$
$$= 0.$$

This leads to a symmetric Nash equilibrium lobbying effort of

$$L_i^* = \frac{2}{9} \left[\frac{\bar{T}^2}{2M} + \frac{\bar{T}(M - \bar{T})}{M} \right].$$

As discussed above, letting player C be a residual claimant does not affect the Nash equilibrium lobbying effort if players are risk neutral.

Case 3: R Known After Permit Awards

As discussed above, there is no closed-form solution for the symmetric Nash. We solve for the Nash equilibrium lobbying efforts numerically for different values of the risk aversion parameter θ (including $\theta = 0$ for risk neutrality); the results are presented in Figures A3 and A4.

For the risk-neutral case, the first-order conditions derived above take on a simpler form:[25]

$$\frac{\partial E[x_A]}{\partial L_A} = -s_A T + (M - s_A T)(s_A' T - 1)$$
$$= M(s_A' T - 1) - s_A s_A' T^2$$
$$= 0$$
$$\Rightarrow \frac{L_B + L_C}{(L_A + L_B + L_C)^2} T \left(1 - \frac{s_A T}{M}\right) - 1 = 0;$$

$$\frac{\partial E[x_B]}{\partial L_B} = -T s_A - (s_A' T + 1) s_B T + (M - s_A T - s_B T)(s_B' T - 1)$$
$$= -s_A' s_B T^2 + (M - s_A T - s_B T) s_B' T - M$$
$$= 0$$
$$\Rightarrow T \frac{L_A + L_C}{(L_A + L_B + L_C)^2} - \frac{T^2}{M} \frac{L_A^2 + L_C L_A + L_C L_B}{(L_A + L_B + L_C)^3} - 1 = 0;$$

$$\frac{\partial E[x_C]}{\partial L_C} = -(s_A + s_B)T - (s_A' T + s_B' T + 1)(T - s_A T - s_B T) + (M - T)(s_C' T - 1)$$
$$= -T(s_A' T + s_B' T)(1 - s_A - s_B) + (M - T) s_C' T - M$$
$$= 0$$
$$\Rightarrow \frac{T^2}{M}\left(\frac{L_A + L_B}{(L_A + L_B + L_C)^2}\right)\left(1 - \frac{L_A + L_B}{(L_A + L_B + L_C)}\right) + \frac{T(M - T)}{M}\left(\frac{L_A + L_B}{(L_A + L_B + L_C)^2}\right) - 1$$
$$= -\frac{T^2}{M} \frac{(L_A + L_B)^2}{(L_A + L_B + L_C)^3} + T \frac{L_A + L_B}{(L_A + L_B + L_C)^2} - 1 = 0.$$

[25] Note that we make use of the following derivative: $\frac{\partial s_i}{\partial L_j} = -\frac{L_I}{\sum_{k \in I} L_k}$.

Figure A1.3: Nash Equilibrium Lobbying Efforts as a CRRA Parameter (θ), by Player across Treatments

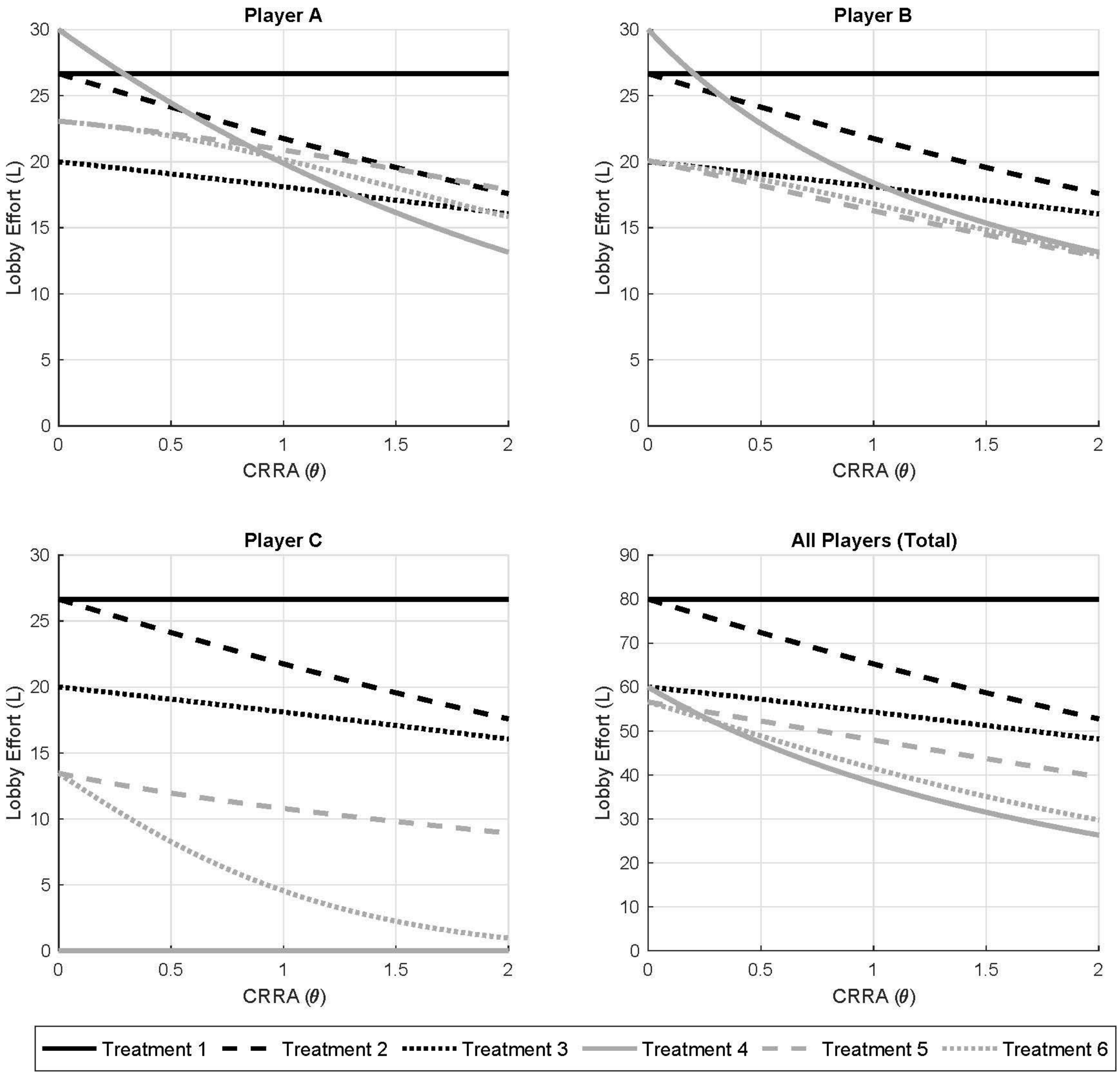
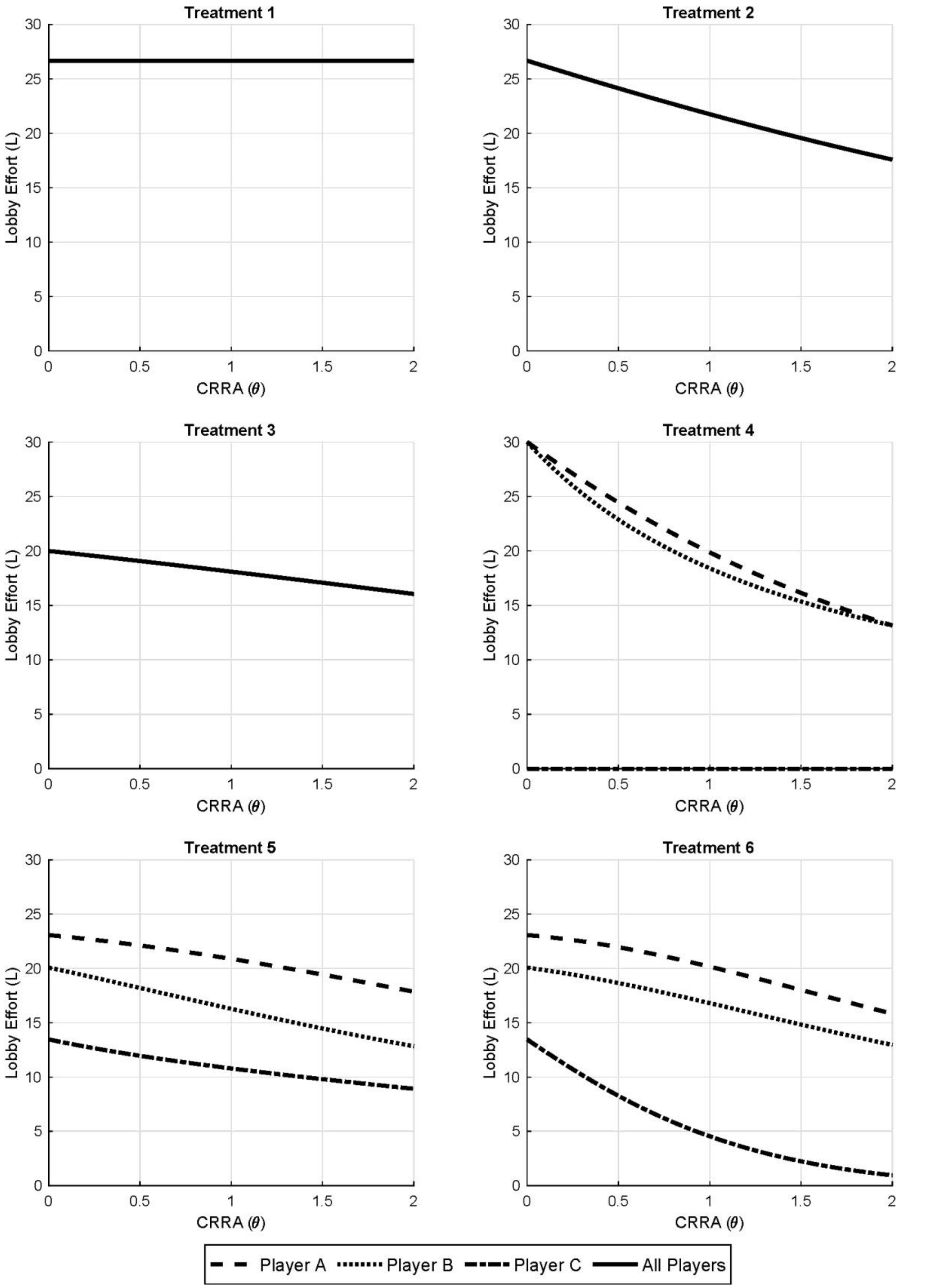


Figure A1.4: Nash Equilibrium Lobbying Efforts as a CRRA Parameter (θ), by Treatment across Players



Appendix 2. Auxiliary Estimates of Lobbying Effort and Risk Attitudes

The power of the risk elicitation protocol to explain lobbying effort is further examined through estimation results that parallel the primary hypotheses explored in the main text. As noted in the text and the accompanying Table 4, the risk elicitation does have some explanatory power with respect to the Uncertainty Hypothesis. Consistent with theory, we find that it is the extremely risk averse with the most robust reduction in lobbying effort when moving from the certain prize treatment (T1) to the uncertain prize (T2). However, the risk categories provide an incomplete explanation. Our prior is that they may provide a useful ranking of subjects with respect to risk attitude, rather than a precise parametric estimate. We review and summarize the benefits and limitations after reviewing the evidence with respect to the Residual Claimant, Partial Payment, and Timing Hypotheses. Within the symmetric treatments we report separate results by risk category. For those in the asymmetric treatment results are reported by risk category and player role.[26]

Residual Claimant Hypothesis

Results related to the Residual Claimant Hypothesis, Table 5 in the main text, are reported in Table A2.1. Theory developed in Appendix 1 predicts that Players A and B should not substantially change their behavior between Treatments 5 and 6. However, Player C should reduce their effort in Treatment 6 with the most risk averse implementing the most substantial reductions. Theory is largely supported with respect to roles A and B. With the exception of the risk neutral (RN) group in role B, there are no significant effort differences in any risk category. The risk categorizations do not help us explain the increase in effort for player C. Theory leads us to expect an increase among the risk seeking (RS). While that is nominally the case, it is actually the extremely risk averse (XRA) group that is primarily responsible for the puzzling increase in effort noted in the main text.

[26] Results of the fixed-effects models are robust to the calculation of standard errors using the wild bootstrapping procedure.

Table A2.1. Residual Claimant Hypothesis: Lobbying Effort Between Asymmetric Treatments (T5 and T6)

Player A	Risk Seeking	Risk Neutral	Risk Averse	Moderately Risk Averse	Extremely Risk Averse
Residual Claimant	-1.482	-1.500	-1.038	-1.388	0.035
(T6)	(2.85)	(2.21)	(2.32)	(2.40)	(4.03)
Constant	38.628***	33.852***	33.815***	35.296***	29.225***
	(1.53)	(1.03)	(1.16)	(1.21)	(2.00)
N	160	216	1019	771	248
Player B					
Residual Claimant	-2.082	3.393*	-0.806	-1.302	0.859
(T6)	(2.71)	(1.56)	(0.70)	(0.87)	(2.58)
Constant	30.301***	23.222***	26.141***	27.318***	22.168***
	(1.29)	(0.82)	(0.35)	(0.43)	(1.32)
N	149	234	1000	770	230
Player C					
Residual Claimant	2.722	-0.974	2.756	1.823	5.616*
(T6)	(5.70)	(3.21)	(1.89)	(02.15)	(2.51)
Constant	29.199***	19.074***	17.961***	18.098***	17.561***
	(2.77)	(1.64)	(0.94)	(1.07)	(1.23)
N	171	230	981	739	242

*p<0.1; **p<0.05; ***p<0.01. Includes subject fixed effects. Robust standard errors are clustered at the session-level. Compare to Table 5. in the body of the paper.

Partial Prize Hypothesis

With respect to the Partial Prize Hypothesis we distinguish between the symmetric and asymmetric cases. Table A2.2a presents evidence for the symmetric case. Signs on coefficients are all negative as we would expect. The difference is significant for risk averse (RA) and moderately risk averse (MRA) subjects, and narrows for the XRA, consistent with theory. Contrary to theory, we would also expect negative and significant results at least as large as seen among the RA for the RN and RS categories.

With respect to the asymmetric case, predictions are quite different. For Player A, we expect negative coefficients on the Cap parameter except for the XRA group, which should increase effort levels in Treatment 5. We do see negative coefficients for all risk categories; however, the result is not significant for either of the extreme categories (RS and XRA). The trend to insignificance is consistent with theory for the XRA but not for the RS. For Player B, we expect negative coefficients but diminishing in magnitude as subjects become more risk averse – paralleling the symmetric case. We do observe lower efforts for the risk averse as expected; however, the RS and RN cases are anomalous as we expect the effects to be greater for those groups. The predictions for Player C are the most striking in that effort should fall to zero in Treatment 4 yielding positive coefficients on the Cap independent of risk attitude. We would expect these coefficients to decrease with increases in risk aversion. Here we observe no significant differences across the treatments for any risk category, although the RN is nominally positive and XRA negative, suggesting a very noisy comparative static effect consistent with theory despite the lack of a strong treatment response.

Table A2.2a. Partial Prize Hypothesis Test: Lobbying Effort in Symmetric Treatments (T2 and T3)

	Risk Seeking	Risk Neutral	Risk Averse	Moderately Risk Averse	Extremely Risk Averse
Cap (T3)	-0.015	-2.344	-4.668**	-5.514**	-0.916
	(5.13)	(3.38)	(1.87)	(2.03)	(1.94)
Constant	34.340***	31.971***	31.624***	32.071***	29.641***
	(2.56)	(1.69)	(0.93)	(1.01)	(0.97)
N	400	680	3480	2840	640

*p<0.1; **p<0.05; ***p<0.01. Includes subject fixed effects. Robust standard errors are clustered at the session-level.

Table A2.2b. Partial Prize Hypothesis Test: Lobbying Effort in Asymmetric Treatments (T4 and T5)

Player A	Risk Seeking	Risk Neutral	Risk Averse	Moderately Risk Averse	Extremely Risk Averse
Cap (T5)	-2.146	-6.203*	-4.339*	-5.1000*	-1.903
	(3.36)	(2.82)	(2.05)	(2.59)	(1.96)
Constant	39.341***	40.057***	38.207***	40.214***	31.763***
	(1.54)	(1.48)	(1.03)	(1.29)	(1.02)
N	161	221	1008	767	241
Player B					
Cap (T5)	0.420	-1.821	-2.018*	-2.145	-1.603
	(4.36)	(2.01)	(1.00)	(1.16)	(2.12)
Constant	29.975***	25.557***	28.148***	29.450***	23.965***
	(2.26)	(0.99)	(0.50)	(0.68)	(1.00)
N	150	228	1009	770	239
Player C					
Cap (T5)	3.419	-1.940	-0.925	-0.506	-2.205
	(3.51)	(2.31)	(2.17)	(2.61)	(1.89)
Constant	24.947***	20.906***	19.608***	19.341***	20.447***
	(1.83)	(1.12)	(1.09)	(1.30)	(0.97)
N	169	231	983	743	240

*p<0.1; **p<0.05; ***p<0.01. Includes subject fixed effects. Robust standard errors are clustered at the session-level.

Timing Hypothesis

The timing hypothesis examines behavior between subjects across the symmetric and asymmetric conditions. Table A2.3a. examines the case in which there is no prize cap (T2 and T4) and Table A2.3b where the cap exists (T3 and T5). For the no cap case: for Player A we expect positive coefficients on T4 except for the XRA category where it should be negative. In fact, all coefficients are positive and the one for the MRA group is strongly significant. For the XRA the effect diminishes (insignificant) but does not become negative as predicted. For Player B, although theory predicts the same dynamic, we observe negative coefficients, which are expected only for the XRA category, across all subjects. The coefficients are significant for the aggregated risk averse (RA) group and for the RN. For Player C we expect large negative coefficients across all categories which we do observe – although insignificant for RN.

The treatments that include the cap in Table A2.3b. yield some similar results to the no cap treatments. However, it should be noted that the range of differences in predicted effort levels across risk categories is smaller than for the no cap comparison. For Player A, it is again the MRA group demonstrating significantly higher effort levels. The differences narrow for the XRA though do not become negative as theory predicts. Results for RS and RN are also noisy, but positive as expected. For Player B, we expect negative coefficients which, with the exception of the RA group we do observe. However, none are significant. For Player C, we expected large negative coefficients; however, the predicted variation across risk groups is small. We observe consistent large decreases in effort consistent with theory, although the RN estimate is noisy and not significant.

Table A2.3a. Timing Hypothesis Test: Lobbying Effort in Full Uncertain Prize (T2 and T4)

Player A	Risk Seeking	Risk Neutral	Risk Averse	Moderately Risk Averse	Extremely Risk Averse
Asymmetric (T4)	2.068	7.447	6.507***	7.915***	2.593
	(5.30)	(4.71)	(2.41)	(2.55)	(3.48)
Constant	36.820***	32.635***	31.792***	32.313***	29.504***
	(3.30)	(4.19)	(1.08)	(1.15)	(2.48)
N	152	221	1079	843	236
Player B					
Asymmetric (T4)	-3.206	-8.625*	-3.231**	-2.526	-4.519
	(4.12)	(4.76)	(1.51)	(1.88)	(3.29)
Constant	33.491***	34.020***	31.542***	32.202***	28.596***
	(2.98)	(3.79)	(0.82)	(0.93)	(2.30)
N	137	236	1084	849	235
Player C					
Asymmetric (T4)	-8.498**	-7.714	-12.550***	-13.120***	-10.143***
	(3.92)	(5.49)	(1.45)	(1.61)	(3.35)
Constant	33.081***	30.171***	31.733***	32.131***	29.837***
	(2.93)	(3.41)	(1.12)	(1.13)	(2.49)
N	151	223	1077	868	209

*p<0.1; **p<0.05; ***p<0.01. Includes subject random effects. Robust standard errors are clustered at the session-level.

Table A2.3b. Timing Hypothesis Test: Lobbying Effort in Partial Uncertain Prize (T3 and T5)

Player A	Risk Seeking	Risk Neutral	Risk Averse	Moderately Risk Averse	Extremely Risk Averse
Asymmetric (T5)	5.443	4.241	7.662***	9.233***	2.238
	(6.41)	(4.69)	(2.54)	(2.72)	(3.41)
Constant	32.581***	29.697***	26.192***	25.749***	28.149***
	(5.95)	(3.30)	(1.70)	(1.85)	(2.70)
N	130	237	1091	864	227
Player B					
Asymmetric (T5)	-4.095	-6.749	-0.107	1.465	-6.012
	(7.24)	(4.62)	(1.98)	(2.17)	(3.89)
Constant	34.806***	30.490***	26.400***	25.938***	28.660***
	(7.13)	(3.43)	(1.65)	(1.69)	(2.96)
N	155	237	1058	849	209
Player C					
Asymmetric (T5)	-7.486	-6.701	-9.655***	-9.114***	-11.689***
	(7.67)	(5.19)	(2.14)	(2.69)	(3.76)
Constant	35.190***	26.953***	27.832***	27.516***	29.117***
	(6.45)	(3.36)	(1.38)	(1.48)	(2.87)
N	155	206	1091	847	244

*p<0.1; **p<0.05; ***p<0.01. Includes subject random effects. Robust standard errors are clustered at the session-level.

Summarizing results, we observe that the risk elicitation does provide insight into behavior that is in many cases consistent with theory regarding the direction of effects. However, estimates are noisy relative to theoretical predictions, and particularly at the extremes (RS and XRA) we find some puzzling results. It should be noted that these two groups are the smallest and so power to detect differences is muted. Further, it may be that such extreme preferences represent some confusion with the protocol rather than a reliable measure of risk attitude. In addition, with respect to limitations, the contest environment—particularly in the asymmetric treatments—may present cognitive demand that are quite different than the pairwise evaluation of lotteries. The reduction axiom may fail in these settings. Finally, it should be noted that rational actors should be affected by other issues. For example, in Table 4 we observe that the RS group nominally reduces effort levels in the Uncertain treatment. Although inconsistent with risk seeking, this may be rational given heterogeneous preferences and beliefs about those preferences. This suggests an avenue for further research. Further study of heterogeneous preferences and beliefs should lead to further insights into existing puzzles with respect to both the mean and variance of effort levels in contest experiments.

Appendix 3. Subject Instructions

The contest experiment was developed using oTree and instructions were displayed on a web browser. Below, we have pasted the experiment script that was read to subjects during the first part of each experiment. As discussed in the manuscript, all subjects completed part 1, a Holt-Laury multiple price list risk elicitation task, before moving to the contest experiment in Part 2. Screenshots of the instructions in Part 2. are pasted below just as they appeared to subjects for Treatment 5. Other treatments were similar and thus are not presented. However, copies of instructions for all treatments are available upon request.

Before experiment:

Take a seat at any computer with an active screen and a set of instructions. Please put your phones away for the remainder of the session. For this experiment, no one can move on until *everyone* has completed each part, so it is important that you focus on promptly completing each task. If everyone focuses, the experiment will be done relatively quickly.

Part 1:

In front of you is a pencil and a set of instructions for completing Part 1 of the experiment. The first page contains written instructions and the last two pages contain a series of tables. On your computer screen you should see an identifier code made up of letters and numbers. Take a moment to write your ID code at the top of each page for Part 1, and please write legibly.

Wait for everyone to write their ID on their sheets.

Now I will read the instructions for Part 1 out loud. Please follow along on your instructions sheet, and raise your hand if you have any questions.

Read instructions.

Are there any questions?

Please take a few minutes to make your decisions.

Wait about five minutes for everyone to finish.

Part 2:

Now we will begin Part 2 of the experiment. Your earnings from Part 2 will be in addition to your earnings from Part 1 of the experiment. At the end of the experiment, we will revisit Part 1 to calculate your earnings for that part.

This portion of the experiment will be done on the computer, so you can set your pencil and Part 1 pages aside for now.

Please read all of the instructions carefully, and raise your hand if you have any questions. At the end of the instructions, there are two learning comprehension questions that will not count toward your earnings.

Thank you for not using your cell phones during the experiment. You may begin reading the instructions. Feel free to make notes on the back of your decision sheets.

Instructions for Part 2

This part of the experiment consists of 20 decision-making periods. At the beginning of each period, you placed into a group with 2 other participants. The members of your group will be selected at random each period and so the composition of your group will change each period.

The identities of the participants in your group will not be disclosed, that is, participants will be anonymous.

Each period, everyone in your group will be given an initial endowment of 60 ECUs. In addition, there will be a variable prize amount each round that will be distributed as described below.

The *variable prize* can range in value from 0 to 240 ECUs, and the precise amount will be selected at random by the computer in each round. Each value from 0 to 240 is equally likely to be chosen, and thus the average or expected value of the variable prize is 120 ECUs.

The actual amount of the prize selected at random in a specific round is independent of the amounts selected in any other round.

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How the award is distributed

Variable prize amounts can be of two types; either available or unavailable. Available variable prize amounts are added to participants' payoffs according to the rules discussed below. Unavailable variable prize amounts are not added to participants' payoffs. All of the variable prize less than or equal to 120 ECUs is available to the participants. Variable prize amounts above 120 ECUs are unavailable.

Your decision in the game, and the decisions of others, affects how the available amount of the variable prize is distributed among the 3 participants in your group.

At the start of the session you will be randomly assigned a Prize Order which determines the order in which shares of the available variable prize amount will be distributed. You may be Participant 1, 2, or 3, with the number indicating your Prize Order. If you are participant 1 you receive your payoff first, participant 2 receives second, and participant 3 receives last.

In each round you have the opportunity to submit or "bid" some, none or all of your initial endowment of 60 ECUs.

The more you bid, the larger your share of the available variable prize. The more other participants in your group bid, the smaller your share of the available variable prize.

Thus, your share of the available variable prize is given by the number of ECUs you bid divided by the total number of ECUs all three participants in your group bid.

$$Your\ Share\ of\ the\ Available\ Variable\ Prize = \frac{your\ bid}{sum\ of\ all\ 3\ bids\ in\ your\ group}$$

If all participants bid zero, the Prize is shared equally among all three participants in the group.

The amount of the prize you receive is based partly on the order in which the prize is distributed. Participants will receive their shares in order of priority associated with Prize Order; that is priority is given first to Participant 1, then to Participant 2, and finally to Participant 3.

The Prize Order is important because the variable prize changes each period and can be as low as 0 and as high as 240. The computer will make allocation decisions based on 50% of 240, or 120 ECUs, which is also equal to the average or expected value.

The variable prize selected by the computer each round can be less than or more than 120 ECUs. Let's consider when the variable prize is less than or equal to 120 and when the variable prize is more than 120.

Case 1: Variable prize is less than or equal to 120

If the variable prize is equal to 120 ECUs, then shares will be distributed to all participants in light of a 120 prize.

If all participants bid the same, then each participant will receive 1/3 of 120 or 40 ECUs each.

If participants bid different amounts, each participant will be paid based upon their bid share. Suppose that the bid share of participant 1 is 50%, participant 2, 20% and participant 3, 30%. Participant 1 would receive 50% of 120 or 60 ECUs, participant 2 would receive 20% of 120 or 24 ECUs, and participant 3 would receive 30% of 120 or 36 ECUs.

Suppose the variable prize is equal to 80 ECUs. The 80 units will be distributed to participants based on their bid shares of the expected value of 120, up to the point that the prize of 80 is fully allocated.

If all participants bid the same, the maximum each participant would receive is 120/3 = 40 ECUs. With a prize of only 80, participant 1 would receive 40 ECUs, participant 2, 40 ECUs and participant 3, 0 ECUs.

If participants bid different amounts, participants still receive a share of 120 ECUs until the prize of 80 is exhausted. Suppose, that the bid share of participant 1 is 50%, participant 2, 20% and participant 3, 30%. Participant 1 would receive up to 50% of 120 or 60. After the allocation to Participant 1 there is only 20 remaining of the 80 ECU prize (80-60). Participant 2 could receive up to 20% of 120, or 0.2 x 120 = 24. However, since 24 ECUs would exceed the maximum prize (60 + 24 = 84), participant 2 will only receive 20 ECUs. Although participant 3 has a positive bid share, they would receive 0 ECUs because the prize of 80 has been fully allocated.

With a prize less than 120, in most cases Participant 1 will receive their full bid share. Participants 2 and 3 will often receive less than their full bid share, as in the example provided. The prize will be allocated up to the point that the variable prize is exhausted.

Case 2: Variable prize more than 120

When the variable prize is greater than 120, shares will be distributed to participants based on their bid shares of the expected value of 120. Any variable prize beyond 120 ECUs will not be allocated to any participant, it is unavailable.

Suppose the variable prize is equal to 150. In this case, 120 ECUs will be distributed to participants based on their bid shares and 30 ECUs will be unavailable.

If participants bid the same amount, the maximum each participant would receive is 120/3 = 40 ECUs. With a prize of 150, participant 1 would receive 40, participant 2, 40 and participant 3, 40. The difference between 150-120, 30 ECUs, would not be allocated to any participant.

If participants bid different amounts, participants still receive a share until the 120 ECUs are exhausted. For a variable prize of 150, suppose that the bid share of participant 1 is 50%, participant 2, 20% and participant 3, 30%. Participant 1 would receive up to 50% of 120 or 60, participant 2 would receive 20% of 120 or 24, and participant 3 would receive 30% of 120 or 36 ECUs. Again, only 120 ECUs are allocated, the residual of 30 (150-120) is not allocated to any participant.

In summary, with a realization more than 120, all participants will receive their full bid share. Only 120 units will be allocated to participants and any residual is unavailable and is not awarded to any participant.

Please raise your hand if you have any questions.

The remainder of the instructions include:

- An example of the decision screen.
- A complete discussion of the process through which your earnings are determined.
- An example of the share calculations.

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Instructions for Part 2

Round 1 of 60

Total available prize this round: 240

Your harvest position this round: P1

You can bid up to 60 ECUs.

Your bid :

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Round	Prize Order	Your Bid	Total Bids	Maximum Prize	Prize Amount	P1's Share	P2's Share	P3's Share	Earnings (in ECUs)

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Instructions for Part 2

Your earnings for

After the amount of the variable prize is determined and the shares are calculated, potential earnings for the period are calculated.

Potential Earnings = Endowment + Share of Prize–Your Bid = 60 + Share of Prize–Your Bid

The results from 2 of these 20 periods will be chosen at random at the end of the experiment. To select the rounds that count toward your final earnings, the experimenter will roll a die 2 times in front of everyone. The die rolls will determine which rounds count toward your final earnings.

The earnings from these 2 rounds will be converted to dollars and paid to you in cash at the end of the experiment. In addition, you will also receive your earnings from all other parts of the experiment.

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Instructions for Part 2

Example of the Share Calculation

After each participant bids, the computer will make a random draw which will determine the value of the variable prize and calculate the shares. The random draw will be a number between 0 and 240 as discussed earlier. Finally, the computer will calculate your period earnings based on your bid and your share of the variable prize.

This is a hypothetical example used to illustrate how the computer calculates shares. Suppose Participant 1 bids 15 ECUs, Participant 2 bids 10 ECUs, and Participant 3 bids 0 ECUs. In total, participants bid 25 ECUs (10+15+0). The share of the variable prize is 10/25 = 40% for Participant 1; 15/25 = 60% for Participant 2; and 0/25 = 0% for Participant 3.

Suppose the variable prize selected by the computer is 120.

Participant 1 would earn [60 + .4(120) – 15] = [60 + 48 - 15] = 95 ECUs.

Participant 2 would earn [60 +.6(120) – 10] = [60 + 72 - 10] = 122 ECUs.

Participant 3 would earn [60 +0(120) – 0] = [60 + 0 - 0] = 60 ECUs.

At the end of each period, your bid, the sum of other bids in your group, the value of the variable prize, your share of the variable prize and the potential earnings for the period are reported on the outcome screen. Once the outcome screen is displayed, you may record your results for the period on your Personal Record Sheet under the appropriate heading if you wish.

Are there any questions? If so, please raise your hand.

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Instructions for Part 2

Suppose that Participant 1 bids 5, Participant 2 bids 5 and Participant 3 bids 10. Suppose the award selected at random by the computer is 200 ECUs. What does each person earn, including any unused portion of the endowment of 60?

Participant 1

Participant 2

Participant 3

Submit Answers

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Instructions for Part 2

Suppose that Participant 1 bids 5, Participant 2 bids 5 and Participant 3 bids 10. Suppose the award selected at random by the computer is 200 ECUs. What does each person earn, including any unused portion of the endowment of 60?

Participant 1	85
Participant 2	85
Participant 3	110

Submit Answers

Correct Response: The total bid is equal to 5+5+10 = 20. Participant 1's share is 5/20 = 1/4, Participant 2's share is 5/20 = 1/4, and Participant 3's share is 10/20 = 1/2.

The maximum available prize is 120, any prize above the maximum prize is unavailable. In this example, 80 ECU are unavailable (200-120).

The maximum possible payoff from a Prize for each participant is

- 1/4 x 120 = 30 ECUs for Participant 1
- 1/4 x 120 = 30 ECUs for Participant 2
- 1/2 x 120 = 60 ECUs for Participant 3

Earnings from the Prize is limited to 120, and earnings per Participant is equal to

- 30 for Participant 1
- 30 for Participant 2
- 60 for Participant 3

Given that each Participant starts with an endowment of 60 ECUs, total earnings for

- Participant 1 are 60 - 5 + 30 = 85 ECUs
- Participant 2 are 60 - 5 + 30 = 85 ECUs
- Participant 3 are 60 - 10 + 60 = 110 ECUs

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Instructions for Part 2

Suppose that Participant 1 bids 5, Participant 2 bids 5 and Participant 3 bids 10. Suppose the award selected at random by the computer is 80 ECUs. What does each person earn, including any unused portion of the endowment of 60?

Participant 1

Participant 2

Participant 3

Submit Answers

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Instructions for Part 2

Suppose that Participant 1 bids 5, Participant 2 bids 5 and Participant 3 bids 10. Suppose the award selected at random by the computer is 80 ECUs. What does each person earn, including any unused portion of the endowment of 60?

Participant 1	85
Participant 2	85
Participant 3	70

Submit Answers

Correct Response: The total bid is equal to 5+5+10 = 20. Participant 1's share is 5/20 = 1/4, Participant 2's share is 5/20 = 1/4, and Participant 3's share is 10/20 = 1/2.

The maximum available prize is 120, any prize above the maximum prize is unavailable.

The maximum possible payoff from a Prize for each participant is

- 1/4 x 120 = 30 ECUs for Participant 1
- 1/4 x 120 = 30 ECUs for Participant 2
- 1/2 x 120 = 60 ECUs for Participant 3

Because the award is only equal to 80, earnings from the Prize will be

- 30 for Participant 1
- 30 for Participant 2
- 20 for Participant 3 because only 20 ECU are available after Participant 1 and Participant 2 have received their share of the prize [80 – 30 – 30].

Given that each Participant starts with an endowment of 60 ECUs, total earnings for

- Participant 1 are 60 - 5 + 30 = 85 ECUs
- Participant 2 are 60 - 5 + 30 = 85 ECUs
- Participant 3 are 60 - 10 + 20 = 70 ECUs

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Round 1

Maximum available prize this round: 120

Your Prize Order this round: P2

You can bid up to 60 ECUs.

Your bid :

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History

Round	Prize Order	Your Bid	Total Bids	Maximum Prize	Prize Amount	P1's Share	P2's Share	P3's Share	Earnings (in ECUs)