Damaging conflict: All-pay auctions with negative spillovers and bimodal bidding*

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Abstract

We study whether the presence of a negative externality in an all-pay auction affects players' behavior in the laboratory. Based on a model with risk-neutral preferences it should not, as the game's equilibrium is the same in both environments in terms of strategies, and our experimental evidence provides some support in that regard. Subjects' bids exhibit the same patterns in both treatments, and average bids are not significantly different from the expected equilibrium bid whether the externality is present or not. Bimodal bidding patterns are also observed in both our treatments, however, and while commonly observed in other all-pay auction experiments (without externalities), these patterns are not consistent with our risk-neutral model's predictions. Bimodal bidding *is* consistent with a model incorporating preferences based on prospect theory, but that type of model is difficult to reconcile with the fact that the observed bid distributions in the treatments with and without damages are not sinificantly different from one another. The presence of an externality therefore does not seem to alter competitive behavior in the laboratory, but this in itself provides evidence questioning the leading behavioral explanation of bimodal bidding.

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1 Introduction

We present the results of laboratory experiments on a type of all-pay auction game that incorporates negative externalities. We term these games *contests with damages*.

Contests with damages are two-player games in which each player simultaneously chooses an amount of spending to win a prize of common value. The player who spends the most wins the prize with certainty, but both players sacrifice their spending regardless of whether they win or lose as in the standard all-pay auction. The difference from the standard all-pay auction is that each player's spending also imposes some amount of "damage" in terms of increased cost upon the other player regardless of winning or losing. The players' own spending is therefore not only costly to themselves, but also injurious to their rival.

One interpretation of this model could be a political lobbying contest in which both parties spend to win office. The spending is sunk on both sides in pursuit of victory, but in the process each also damages the opposing side's reputation, win or lose. Similarly, the model could represent a battlefield conflict situation, with spending in the pursuit of victory by one side also felt (in payoff terms) in the form of damaging material consequences for the other. More generally, one could interpret the concept of the model as capturing a notion of destructive competition: as a player spends more to win the prize, there is an additional effect that harms their opponent in payoff terms, but that effect does not improve their own payoff.

A model of contests with damages in which players have risk neutral preferences is especially interesting for experimental analysis because it is a specific variant of the "rank-order spillover" contest model developed by Baye et al. (2009), which provides testable results. While the general spillover model's parameters allow for a wide variety of contests with both positive and negative externalities, we focus on the version that captures an all-pay auction with only negative externalities exerted equally by both players. Baye et al. (2009) established that this specific version has an identical symmetric equilibrium to the standard all-pay auction, providing an opportunity for comparison in terms of subject behavior: players should exhibit the same equilibrium levels of spending (on average) whether or not damages are present in the model. Our results support that prediction.

Comparing the results of our experimental treatments of two-player all-pay auctions with and without damages, we find that subjects behave almost identically in either case. Average bids were not significantly different across treatments, and were equal to about half subjects' valuation for the prize as predicted by the model with risk-neutral preferences. In addition, however, the treatments displayed almost identical patterns of *bimodal* bidding, with large proportions of subjects choosing minimal or maximal bids. Previous experiments on standard two-player all-pay auctions have also found average bids to be close to the expected equilbrium (Potters et al., 1998), and similar bimodal bidding patterns have been observed in most experimental studies of all-pay auctions (Dechenaux et al., 2015), lending further support to the fact that the behavior of the subjects in our treatment with damages was unaffected by their presence. Bimodal bidding is *not* consistent with equilibrium behavior in the all-pay auction model with risk-neutral preferences, however, with or without damages.

Ernst and Thöni (2013) show that the bimodal bidding patterns commonly observed in all-pay auction experiments are consistent with a model in which players have reference-dependent preferences as proposed by prospect theory, and this is the leading explanation for such results (Dechenaux et al. 2015). The issue is that incorporating such preferences into a model with damages does not lead to the same equilibrium predictions as the model without. Thus, while our results do provide evidence that harming rivals in all-pay auctions has no significant effect on behavior, this contradicts the explanation for bimodal bidding patterns. In a model with reference-dependent preferences, the bimodal patterns should not be identical.

To explain more fully, in the next section we present the all-pay auction model with damages and show that while equilibria are equivalent in expectation when players have risk-neutral preferences, this is not the case with reference-dependent preferences. We then present our experimental setup and results, and finish with a short discussion.

2 Theory and Previous Literature

In the all-pay auctions we study, two players, $i = 1, 2$, simultaneously choose expenditure (effort) levels, $b_i \in [0, \infty)$, to win a prize commonly valued at V. The player choosing the highest expenditure level wins with certainty (with ties broken by the toss of a fair coin), but both parties' expenditure levels are sunk as in the standard all-pay auction with complete information. In addition to the direct cost of the expenditures, however, their expenditures may also inflict damage on one another. When players have risk-neutral preferences, payoffs are specified as

$$u_i(b_i, b_j) = \begin{cases} V - b_i - \gamma b_j & \text{if } b_i > b_j \\ -b_i - \gamma b_j & \text{if } b_i < b_j \\ \frac{1}{2}V - b_i - \gamma b_j & \text{if } b_i = b_j, \end{cases} \tag{1}$$

where the parameter $\gamma \geq 0$ captures the size of the negative externality. If $\gamma = 0$, the game is a standard all-pay auction with complete information. If $\gamma > 0$, the game is a contest with damages; each player's spending is not only a cost to itself, but also damages the other party.

It is well-known (Hillman and Samet, 1987; Baye et al., 1996) that the standard (risk-neutral) two-player all-pay auction with complete information (here the case of $\gamma = 0$) entails a unique symmetric equilibrium of

$$F^*(b) = \frac{b}{V} \text{ on } b \in [0, V],$$

with equilibrium payoffs of zero. Baye et al. (2009) established that the case of the all-pay auction with negative rank-order spillovers (here the case of $\gamma > 0$, what we refer to as a contest with damages) entails the same unique symmetric equilibrium. This makes sense, as the "damages" aspect of the payoff function does not affect the players' individual choice process (accordingly, γ is referred to as a "nuisance" parameter by Baye et al. (2009)). Though equilibrium payoffs differ for the case with damages, at $-(\gamma/2)v$ rather than zero, what is most important in terms of our experimental predictions is that equilibrium expected spending is the same for both cases, at $v/2$. This leads us to the following for our experiments.

Hypothesis. Average bids will be the same in experimental trials of standard all-pay auctions and all-pay auctions with damages.

Though we are the first to include damages in experimental treatments of all-pay auctions, previous studies of standard all-pay auctions have revealed two consistent results that are particularly relevant to our own.[1] First, average bidding does seem to be in line with equilibrium predictions when experiments involve only two bidders (Potters et al., 1998; Ernst and Thöni, 2013), though when experiments involve more than two subjects competing the tendency is to overbid relative to Nash equilibrium (Gneezy and Smorodinsky, 2006; Lugovskyy et al., 2010). Second, regardless of the number of bidders, experimental studies of all-pay auctions have consistently displayed bimodal bidding patterns with subjects placing very low (close to zero) and very high (close to v) bids more frequently than others (Ernst and Thöni, 2013; Dechenaux et al., 2015), contrary to the uniform distribution predicted by theory.

To explain bimodal bidding, Ernst and Thöni (2013) suggest a model with reference-dependent preferences and loss aversion based on prospect theory (Kahneman and Tversky, 1979). Specifically, they employ the value function specified by Tversky and Kahneman (1992):

$$v(x) = \begin{cases} x^{\alpha} & \text{if } x \geq 0 \\ -\lambda(-x)^{\alpha} & \text{if } x < 0, \end{cases} \tag{2}$$

This functional form means that gains and losses are evaluated differently based on a reference point of zero. The parameter $\alpha \in (0, 1)$ implies players are risk-averse in gains but risk-seeking in losses, while the parameter $\lambda > 0$ determines loss-aversion.

Any symmetric mixed-strategy equilibrium for a two-player all-pay auction must satisfy the following:

$$\mathbb{E}u(b_i, F) = \mathbb{E}u_W(b_i, F) + \mathbb{E}u_L(b_i, F) = \mathbb{E}u(0, F) \text{ for all } b \in [0, V], \tag{3}$$

where $\mathbb{E}u_W(b_i, F)$ and $\mathbb{E}u_L(b_i, F)$ are the expected payoffs from winning and losing, respectively, for a player bidding b_i against the mixed strategy F. The following is a more concrete version for our problem, where we denote the equilibrium mixed strategy cumulative distribution function as $\tilde{F}(b_i)$ and the

[1] See Dechenaux et al. (2015) for a survey of experimental research on all-pay auctions.

associated probability density function as $\tilde{f}(b_i)$:

$$\mathbb{E}u(b_i, \tilde{F}(b_i)) = \int_0^{b_i} (V - b_i)^\alpha \tilde{f}(b_j) db_j + \int_{b_i}^{V} (-\lambda(b_i)^\alpha) \tilde{f}(b_j) db_j = 0 \ \text{ for all } \ b \in [0, V].$$

Since the utility from winning $(V - b_i)^\alpha$ and the utility from losing $-\lambda(b_i)^\alpha$ do not depend on b_j, this expression can be simplified considerably to

$$\mathbb{E}u(b_i, \tilde{F}(b_i)) = \tilde{F}(b_i)(V - b_i)^\alpha + (1 - \tilde{F}(b_i))(-\lambda(b_i)^\alpha) = 0 \ \text{ for all } \ b \in [0, V] \tag{4}$$

Solving this equation for $\tilde{F}(\cdot)$ gives the following symmetric equilibrium bidding strategy:

$$\tilde{F}(b_i) = \left(\frac{\lambda(b_i)^\alpha}{\lambda(b_i)^\alpha + (V - b_i)^\alpha} \right), \tag{5}$$

which in turn yields a bimodal density as desired (Ernst and Thöni, 2013).

Inserting damages into the model with reference-dependent preferences is less straightforward than the case of the standard model for two main reasons. First, the expected payoff for not bidding at all, $\mathbb{E}u(0, F_d)$, is no longer equal to zero. This can be seen upon inspection of the expected payoff of not bidding with damages

$$\mathbb{E}u(0, F_d) = -\lambda \int_0^V (\gamma b_j)^\alpha f_d(b_j) db_j,$$

where F_d is the cumulative distribution function used by both players, and f_d is its associated density.

Second, the gains and losses from bidding no longer depend solely on the agent winning or losing. The expected payoff for losing with a bid of b_i is

$$\mathbb{E}u_L(b_i, F_d) = -\lambda \int_{b_i}^{V} (b_i + \gamma b_j)^\alpha f_d(b_j) db_j,$$

and the expected payoff for winning with a bid of b_i is

$$\mathbb{E}u_W(b_i, F_d) = \begin{cases} \int_0^{b_i} (V - b_i - \gamma b_j)^\alpha f_d(b_j) db_j & \text{if } b_i \le V(1-\gamma), \\ \int_0^{\bar{b}} (V - b_i - \gamma b_j)^\alpha f_d(b_j) db_j - \lambda \int_{\bar{b}}^{b_i} (\gamma b_j + b_i - V)^\alpha f_d(b_j) db_j & \text{if } b_i > V(1-\gamma) \end{cases} \tag{6}$$

where $\bar{b} \equiv \bar{b}_j(b_i) = (V - b_i)/\gamma$.

The analogue to Equation 3 for the model with reference-dependent preferences *and* damages is

$$\mathbb{E}u(b_i, F_d^*) = \mathbb{E}u_W(b_i, F_d^*) + \mathbb{E}u_L(b_i, F_d^*) = \mathbb{E}u(0, F_d^*) < 0 \text{ for all } b \in [0, V]. \tag{7}$$

This defines the symmetric equilibirum F_d^*.

In general, there is no reason why $\tilde{F}$ and F_d^* should be the same.

Hypothesis. The distribution of bids will *not* be the same in experimental trials of standard all-pay auctions and all-pay auctions with damages.

3 Experimental design

In each session, subjects are randomly sorted into groups of two. Groups are fixed for the twenty rounds of the experiment.[2] Subjects within each group play a symmetric and complete information all-pay auction with a prize of $USD5$. Group members simultaneously choose unrecoverable bids, the highest of which wins the prize. Ties are broken by fair randomization. After each round, subjects observe both bids and both payoffs. Subjects also observed a history table, which contained this information for all preceding rounds.

Our experiment has two treatments. The first is the standard all-pay auction described above. In the

[2]In all-pay auctions, the subjects are predicted to employ a mixed strategy. If we had used a random re-matching protocol, subjects could rely on the re-matching protocol to ensure that their bids were unpredictable. Thus, the fixed matching protocol encourages subjects to actively randomize, and is a key feature of our experimental design.

second treatment, each subject must pay 20% of the bid of their counterpart, in addition to their own bid. We refer to the former as the "No damages" (ND) treatment, and the latter as the "With damages" (WD) treatment.

In the ND treatment we ran three sessions, with a total of 21 groups.[3] In the WD treatment, we ran four sessions, with a total of 31 groups.[4] All sessions were run at Utah State University. At the beginning of an experimental session subjects were seated at computers separated by dividers to ensure privacy. Subjects were provided with a hard copy of the instructions, which were read aloud by an experimenter.[5] Subjects completed a short quiz prior to begininng the experiment. The computer interface was programmed in z-Tree (Fischbacher, 2007).

Subjects were paid a $7 show-up fee, and began the experiment with $15 to cover losses. Four rounds were randomly selected for payment.[6] Subject payments were rounded up to the nearest $0.25, and paid in private. The average payment was $22.16, with a minimum of $7, and a maximum of $42.00.

4 Results

Each independent observation is a pair. For non-parametric tests we average the pairs over all twenty rounds of the experiment.

[3] In two sessions, there were sixteen subjects. In the third, there were ten subjects.

[4] In two of the sessions there were 20 subjects. One of the remaining sessions had ten subjects, and the other had twelve.

[5] The instructions for the WD treatment can be found in Appendix A.

[6] Three subjects lost more than the starting balance in the four selected rounds, and were only paid their $7 show-up fee. We do not drop this data in our analysis, but our results are robust to doing so.

Table 1: Summary statistics

	Without damage	With damage
Expenditures	2.173	2.346
	(1.859)	(1.943)
Total expenditures	4.347	4.691
	(2.986)	(3.297)
Payoffs	0.327	-0.315
	(2.407)	(2.854)

Notes: Table contains means with standard deviations in parentheses.

Can't reject that expenditures are, on average, in line with theory if preferences are risk-neutral. Without damage: Wilcoxon Signed Rank test, $p = 0.3038$; With damage: Wilcoxon Signed Rank test, $p = 0.7352$

We can't reject that expenditures are equal across treatments. Robust rank order, $p = 0.39702$

We can't reject that total expenditures are, on average, in line with theory if preferences are risk-neutral. Without damage: Wilcoxon Signed Rank test, $p = 0.3038$; With damage: Wilcoxon Signed Rank test, $p = 0.7352$

We can't reject that total expenditures are equal across treatments. Robust rank order, $p = 0.39702$

We can't reject that payoffs are, on average, in line with theory if preferences are risk-neutral. Without damage: Wilcoxon Signed Rank test, $p = 0.3038$; With damage: Wilcoxon Signed Rank test, $p = 0.7352$

Payoffs are lower with damage, in line with theory if preferences are risk-neutral. Robust rank order, $p = 0.39702$

Fitting the experimental data from the no damages case to the mixed strategy cumulative distribution function in Equation 5, we find that the best fit results from setting $\lambda = 2.3043083$ and $\alpha = 0.5623753$. That is, experimental participants display substantial aversion to both loss and risk.

We next use these fitted parameters to demonstrate that the experimental evidence aligns with the

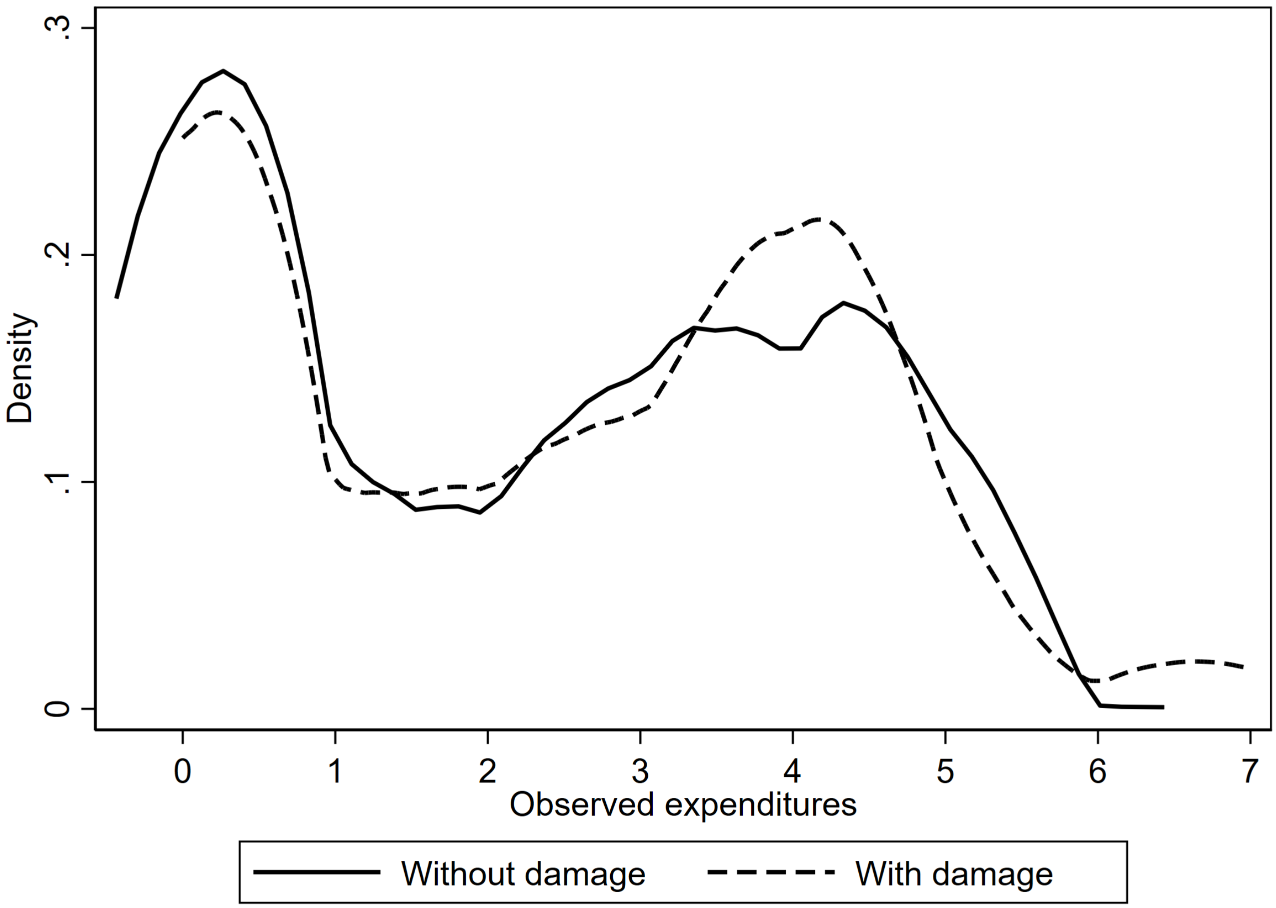

Figure 1: Expenditures with and without damage

predictions of the model. Figure 2 shows the expected payoffs from Player j using the mixed strategy in Equation 5 in the model of reference dependent preferences. The parameters are set at $\lambda = 2.304308$, $\alpha = 0.5623753$, $V = 5$, and $\gamma = 0.2$ (the latter two from the experimental implementation).

The left panel displays Player i's expected value of winning (orange) and losing (blue) for each $b_i \in [0.5]$ when there are no damages and Player j plays the no-damages mixed strategy. We see that these two expected values net out to zero in the red line, which is the total expected value of bidding (i.e., the expected value of winning minus the expected value of losing). Since the expected value of not bidding (i.e., setting $b_i = 0$) is zero when there are no damages, we see that the condition for Player i to play a fully-mixed strategy—that the expected value of playing each bid is equal to the expected value of any other bid and $b_i = 0$ in particular—is met.

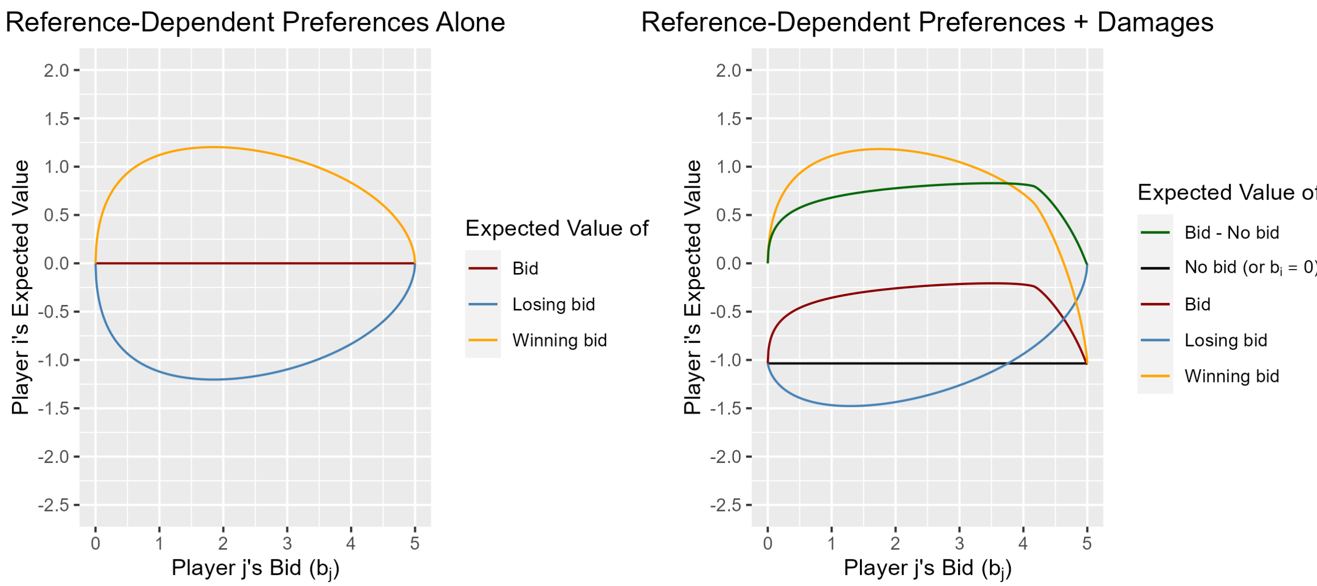

Figure 2: Expected Values against No-Damages Equilibrium Mixed Strategy, Reference-Dependent Preferences

Note that in the left panel, three important expected values all overlap at zero: the expected value of bidding a positive number, the expected value of bidding zero, and the difference between these two. The difference between the expected value of a positive bid and the expected value of a zero bid is exactly what must be equal to zero in order to support a fully-mixed strategy. Importantly, this condition does *not* hold in the right panel, where we change the utility to include damages but continue to use the mixed-strategy for the no-damages case for Player j's mixed strategy. This shows that the fully-mixed strategy for the case with damages must be different from the strategy for the case with no damages.

We can say something even stronger. Because Player i's expected value from a positive bid (the red line) is greater than her expected value of not bidding (the black line) for all $b_i \in (0, 5)$, in order for Player i to play a fully-mixed strategy, the expected value of bidding must be reduced from the red line to the black line for each value of b_i. One of three things needs to happen: the expected value from winning (the orange line) goes down, the expected value from losing (the blue line) goes down, or both.

The value of Player j's bid enters negatively into Player i's expected values from both winning and losing through the damages term γb_j. To reduce either expected value for Player i, the mixed strategy for Player j must shift probability density from lower values of b_j to higher values of b_j compared to the mixed strategy for the no-damages case, $\tilde{F}(b_j)$. It is conceivably possible to also shift some weight to very small values of b_j at the same time as making a more significant shift from intermediate values to higher values so that $F_d^*(b_j)$ does not first order stochastically dominate $\tilde{F}(b_j)$, $F_d^*(b_j)$ must have more probability mass on higher values of Player j's bids.

To further develop intuition, Figure 3 shows the expected values as in Figure 2, but for the case of risk neutral preferences (i.e., $\lambda = \alpha = 1$). Here, we see that the presence of damages shifts the expected values, but does not disturb the mixed strategy.

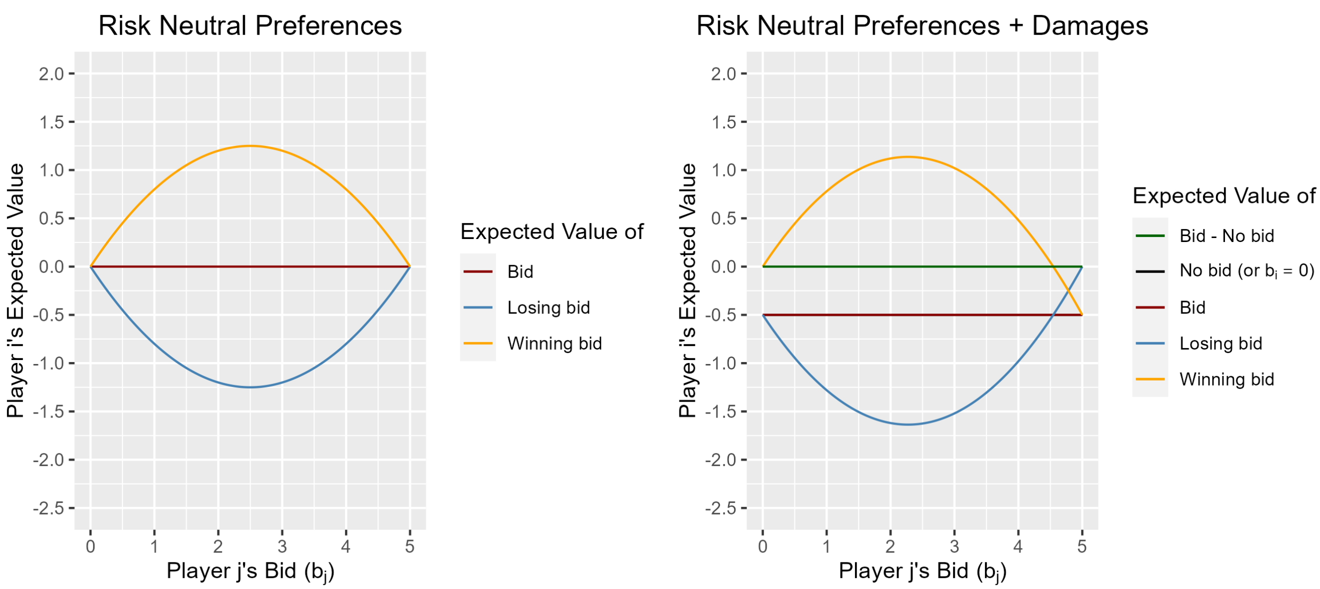

Figure 3: Expected Values against No-Damages Equilibrium Mixed Strategy, Risk-Neutral Preferences

Loss aversion on its own without risk aversion implies that the mixed-strategy must change (See Figure 4), but the probability distribution for the no-damages mixed strategy is not bimodal as desired.

Risk aversion on its own without loss aversion implies that the mixed-strategy must change even more than under loss aversion alone (See Figure 5) and leads to the desired bimodal distribution for the no-damages mixed strategy.

5 Discussion

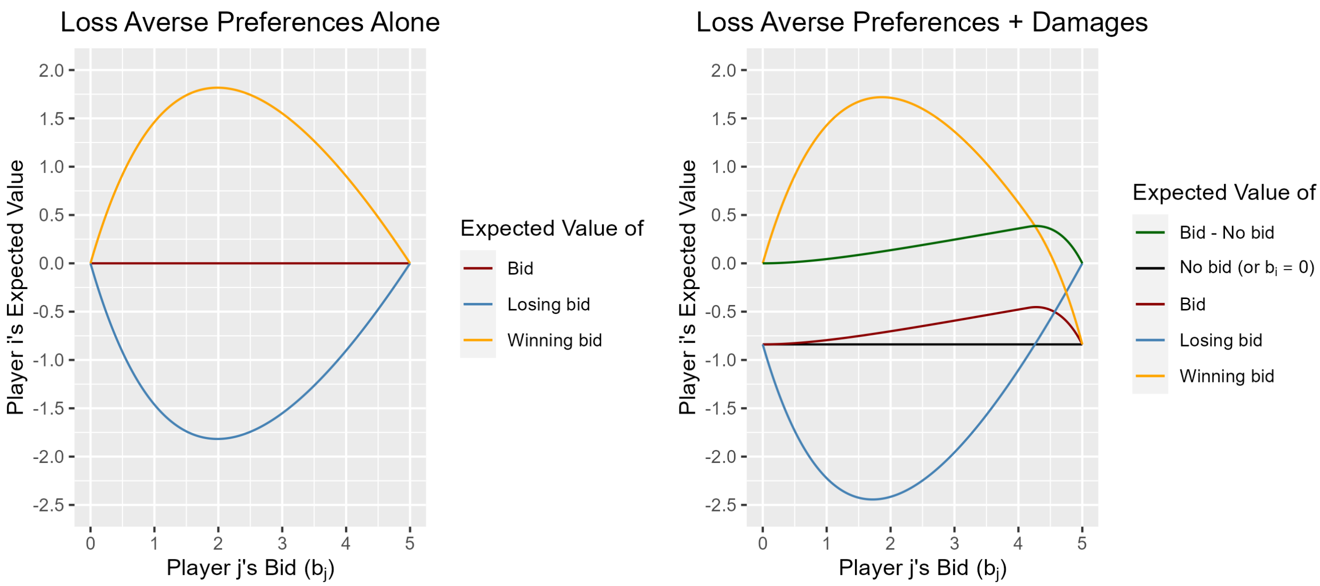

Figure 4: Expected Values against No-Damages Equilibrium Mixed Strategy, Loss-Averse Preferences

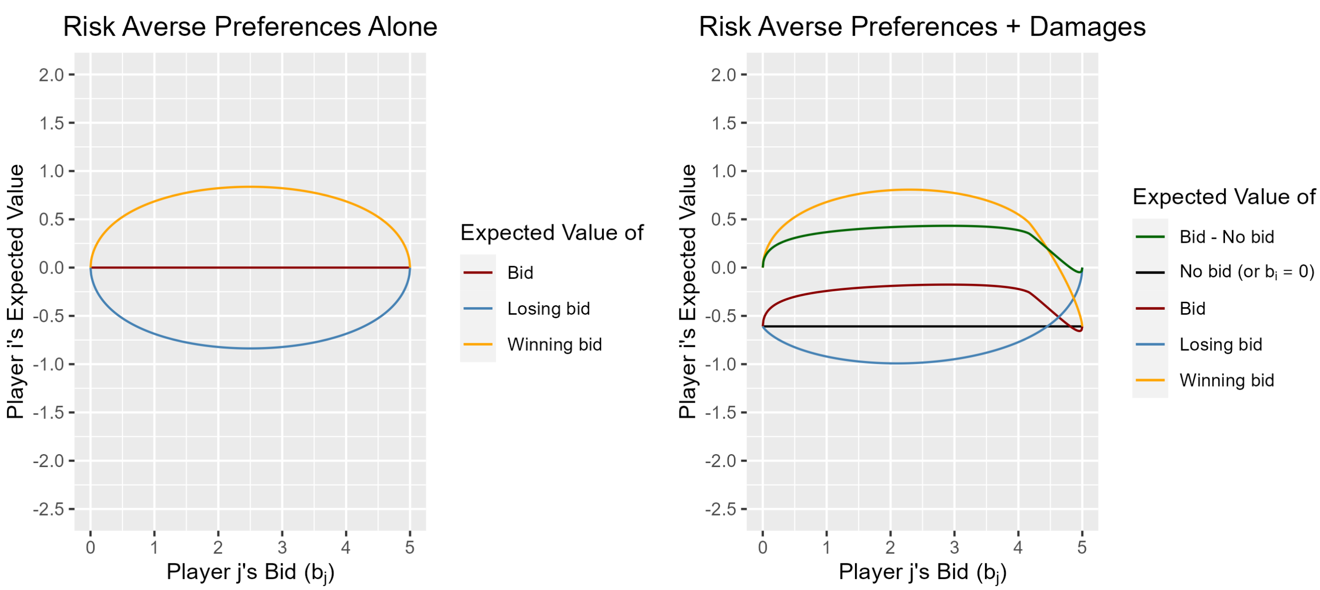

Figure 5: Expected Values against No-Damages Equilibrium Mixed Strategy, Risk-Averse Preferences

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A Instructions

This appendix contains the instructions for the treatment with damages.

Introduction

Welcome to this experiment. The decisions you make during this experiment will determine how much money you earn. You will be paid in cash, privately, at the end of our experiment.

It is important that you remain silent and do not look at other people's work. If you have any questions, or need assistance of any kind, please raise your hand and an experimenter will come to you. If you talk, laugh, exclaim out loud, etc., you will be asked to leave and you will not be paid. We expect and appreciate your cooperation.

The following instructions will explain how you can earn money. We will go over these instructions with you. After we have read the instructions, there will be time to ask clarifying questions. When we are done going through the instructions, each of you will have to answer a few brief questions to ensure everyone understands.

For today's experiment, you will receive an initial payment of $15, in addition to the $7 show-up fee.

Groups

In today's experiment you will be randomly matched with another participant. You will only interact with this other participant through the computer interface, and you will not know who this other participant is.

Available good

In each round, there is a good worth $5 available for each group of two participants. Only one of the two participants in each group will obtain this good; it cannot be divided.

BIDS

In each round, each participant will choose a BID, which is a number between $\$0$ and $\$7$, inclusive. The participant with the highest BID in a group will obtain the good.

If both participants in a group submit the same BID, then the tie is broken randomly, with each participant having equal probability of obtaining the good.

Each participant's BID must be paid, regardless of whether or not they obtained the good.

In addition, the participant who obtains the good pays a percentage of the BID of the other participant in their group. This percentage, which we call a LOSS PERCENTAGE, is 20%.

Similarly, the participant who does not obtain the good pays a percentage of the BID of the other participant in their group. This percentage (which we also call a LOSS PERCENTAGE) is 20%.

Participants will not know the BID submitted by the other participant in their group when they choose their own BID.

PAYOFF of a round

In each round, the participant in the group who submits the highest BID (or who is randomly chosen in the event of a tie), will obtain the good.

The PAYOFF for the round for this participant is

$$(\$5) - (\text{Their Own BID}) - (0.20) \cdot (\text{The BID of the Other Participant})\,.$$

The PAYOFF for the round for the participant who does not submit the highest BID (or who is not randomly chosen in the event of a tie), is

$$\$0 - (\text{Their Own BID}) - (0.20) \cdot (\text{The BID of the Other Participant})\,.$$

Example 1

Suppose that Participant 1 chooses a BID of $\$4.30$, and Participant 2 chooses a BID of $\$0.75$.

Since $4.30 > 0.75$, Participant 1 obtains the good.

His or her payoff for the round is $\$5 - \$4.30 - 0.20 \cdot \$0.75 = \$0.55$.

The payoff of Participant 2, who does not obtain the good, is $\$0 - \$0.75 - 0.20 \cdot \$4.30 = -\$1.01$.

Example 2

Suppose that Participant 1 chooses a BID of $\$2.95$, and Participant 2 chooses a BID of $\$3.60$.

Since $3.60 > 2.95$, Participant 2 obtains the good.

His or her payoff for the round is $\$5 - \$3.60 - 0.20 \cdot \$2.95 = \$0.81$.

The payoff of Participant 1, who does not obtain the good, is $\$0 - \$2.95 - 0.20 \cdot \$3.60 = -\$3.67$.

Participating in a round

At the beginning of each round, you will be asked to enter your BID for the round. Remember that this BID can be any number between $\$0$ and $\$7$, inclusive.

You will choose your BID without knowing the BID chosen by the other participant in your group.

Results of a round

At the end of each round the results of the round will be displayed on your screen. The results you will see are:

1. Whether or not you obtained the good.
2. Your BID.
3. Your LOSS PERCENTAGE.
4. Your Payoff for the round.
5. The BID of the other participant in your group.
6. The LOSS PERCENTAGE of the other participant in your group.
7. The Payoff of the other participant in your group.

In addition, the results of all previous rounds will always be displayed on your screen.

Selecting rounds for payment

Once all 20 rounds of the experiment have been completed, 4 rounds will be randomly chosen for payment. Each of the 20 rounds are equally likely to be chosen for payment.

Your payment for today's session will be the sum of your payoff in each of the 4 rounds randomly chosen for payment and the initial payment of $\$15$. This is in addition to the $\$7$ show-up fee.

Summary

1. In each round there is an available good which is worth $\$5$ to both participants in your group.

2. In each round, both participants in your group will choose a BID, which is a number between $\$0$ and $\$7$, inclusive. The participant in your group who chooses the highest BID will obtain the good. Ties are broken randomly.

3. The PAYOFF for the round of the participant who obtains the good is

$$(\$5) - (\text{Their Own BID}) - (0.20) \cdot (\text{The BID of the Other Participant})\,.$$

4. The PAYOFF for the round of the participant who does not obtain the good is

$$(\$0) - (\text{Their Own BID}) - (0.20) \cdot (\text{The BID of the Other Participant})\,.$$

5. At the end of the experiment 4 of the 20 rounds will be chosen randomly for payment.