Indefinitely Repeated Contests with Incumbency Advantage

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Abstract

We study an indefinitely repeated Tullock contest in which the stage-game winner gains an incumbency advantage in the next stage-game, akin to the competition between political parties in US elections. The advantage is modeled as the incumbent being able to carry over a proportion of their expenditure in the previous contest to the next contest. In controlled laboratory experiments, we find that an incumbency advantage increases total expenditure by a significant amount compared to a baseline in which the incumbent is not inter-temporally advantaged. This result is primarily driven by the fact that incumbents expend substantially more when there is an advantage conditional on their previous expenditure. However, the response by the challenger to the amount of carryover is similar to the challenger's response to lagged expenditure in the absence of an incumbency advantage. This suggests that an incumbency advantage has a direct effect on the incumbent and only an indirect effect on the challenger.

Keywords Infinitely repeated games, Tullock contests, Incumbency advantage, Laboratory experiments

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Declarations
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1 Introduction

Many activities can be viewed as contests where each party makes costly expenditures in the hopes of claiming a prize. Given the wide array of situations that can be viewed as contests, it is unsurprising that a large amount of literature has been devoted to the study of such games. Konrad (2009) and Dechenaux, Kovenock and Sheremeta (2015) provide extensive surveys of the theoretical and experimental work on contests. Although many new papers have been written since those surveys were produced, the vast majority of the literature focuses on one-shot games. In contrast, many situations are better described as dynamically interconnected repeated play games. For example, political parties compete with each other in elections at regular intervals, with the incumbent often being viewed as holding an advantage (e.g., in U.S. presidential elections, the incumbent party has won the majority of campaigns since 1900). In this paper, we explore indefinitely repeated play Tullock (1980) contests by linking successive periods by allowing a portion of the investment made by the winner of the current period to be carried over to the next period (i.e., an incumbency advantage). In controlled laboratory experiments, we find that this linkage leads to significantly greater total investment than in an indefinite horizon game with no dynamic linkage. We also find that when there is winner carryover, there is a direct increase in incumbent expenditure while both players respond positively to the amount of expenditure being carried over. However, these responses are similar to reactions to lagged expenditures in the absence of carryover suggesting carryover only impacts challenger behavior indirectly even though both sides invest more. This excessive spending due to an incumbency advantage is consistent with popular press accounts of exorbitant expenditures by political campaigns.

The work presented in this paper is at the intersection of the literature on indefinitely repeated contests and the literature on contests with carryover. Specifically, Brookins, Ryvkin and Smyth (2021) compares indefinitely repeated and finitely repeated Tullock contests with equal expected durations. They find expenditures to be lower in the indefinitely repeated game, suggesting cooperative behavior between the contestants. They also examine how the discount rate impacts cooperation and report some evidence that cooperation is stronger when the discount rate is lower.[1] Schmitt et al. (2004) consider a finitely repeated contest but consider a setting in which both players can carryover investment from one period to the next. Schmitt et al. (2004) find that carryover is sensitive to the decay rate and shifts expenditure to earlier periods, consistent with theoretical predictions. Interestingly, they also find that total expenditure is lower with carryover than without, even though they still observe overbidding as is common in contest experiments. Finally, Grossmann, Dietl and Lang (2010) also examines a setting where all contestants have carryover and do so in an infinitely repeated contest.[2] Using dynamic programming, they derive equilibrium in steady states and further analyze the effects of revenue sharing on competitive balance between the two players. Baik and Lee (2000) also study carryover, but in a two-period model with a contest structure that is very different from that in Schmitt et al. (2004), Grossmann, Dietl and Lang (2010), and our paper. Specifically, Baik and Lee (2000) considers a tournament with two parallel contests in the first and second stages in which the two first-stage winners compete. Our analysis of winner carryover also contributes to the literature on incumbency in repeated contests. While we allow the incumbent to carry over part of their previous expenditure to the current contest, others have considered different forms of incumbency advantages (e.g., Hafer (2006), Polborn (2006)), Virág (2009), and Häfner and Nöldeke (2019)). Finally, our paper can also be viewed as tangentially related to the literature on learning by doing and psychological momentum in contests. While the marginal cost of effort in a later period can be decreasing in each player's effort in the previous period as they benefit from learning by doing (e.g., Clark and Nilssen (2013)), momentum is typically modeled as an adjustment to the cost of expenditure based on the outcome of the game rather than the player's level of effort in the previous contest (e.g., Chen and Jiang (2017)).

The remainder of this paper proceeds as follows: Section 2 formalizes the contest structure that we consider. Section 3 provides the details of our experimental design, while

[1]Indefinitely repeated contests are themselves a special case of the more general topic of indefinitely repeated play games (see Dal Bo and Frechette (2018) for a survey.)

[2]Both Schmitt et al. (2004) and Grossmann, Dietl and Lang (2010) model carried over expenditures as decaying at a constant rate across periods. Because we consider the case where only the winner has carryover, we model carryover as only surviving for one period.

Section 4 presents the behavioral results, and section 5 concludes.

2 Theoretical Framework

Consider an infinitely repeated Tullock contest with two players who, in each period, compete for a strictly positive prize V by choosing a non-negative expenditure level. We assume that both players are risk neutral and the discount factor for their future income is $\beta \in (0, 1)$ per period. We denote player i's expenditure and his corresponding probability of winning V in period t by $e_{i,t}$ and $p_{i,t}$ respectively. In our benchmark model, we assume the standard Tullock contest success function for both players: $p_{i,t}$ is the ratio of $e_{i,t}$ to the sum of $e_{i,t}$ and $e_{-i,t}$. With carryover, $p_{i,t}$ is also affected by either $e_{i,t-1}$ or $e_{-i,t-1}$ depending on whether it is player i or $-i$ who can carry over part of his expenditure from the previous period.

2.1 No Carryover

We assume that the probability of winning V in period t for player i, where $i = 1, 2$, is

$$p_{i,t} = \frac{e_{i,t}}{e_{i,t} + e_{-i,t}} \tag{1}$$

if $e_{i,t} + e_{-i,t} > 0$, and $p_{i,t} = \frac{1}{2}$ if $e_{i,t} + e_{-i,t} = 0$. Player i's expected payoff in period t is

$$\pi_{i,t} = p_{i,t}V - e_{i,t}. \tag{2}$$

The first order condition for player i in choosing $e_{i,t}$ to maximize $\pi_{i,t}$ given $e_{-i,t}$ is

$$\frac{\partial p_{i,t}}{\partial e_{i,t}}V = \frac{e_{i,t}}{(e_{i,t} + e_{-i,t})^2}V = 1 \tag{3}$$

and therefore his best response in period t can be written as

$$e_{i,t} = \sqrt{e_{-i,t}V} - e_{-i,t}. \tag{4}$$

It follows that there exists a subgame perfect Nash equilibrium supported by the above best response in every period. Specifically, there is a Nash equilibrium in the stage-game where each player chooses the expenditure level of $\frac{V}{4}$ and the expected payoff for each player is $\frac{V}{4}$ each period. However, this is not the only equilibrium in the infinitely repeated contest. There is also a class of subgame perfect Nash equilibria supported by grim trigger strategies. In such equilibria, both players collude by choosing an expenditure that is lower than $\frac{V}{4}$ until one of the players defects. After the defection period, both players play the Nash equilibrium strategy of the stage-game in every period. Suppose that the colluded level of expenditure is c and the defector chooses an expenditure of $c + \epsilon$ where $\epsilon > 0$. Let π_C and π_D be a player's expected payoff in a period that he colludes and defects, respectively. Such collusion can be sustained if

$$\frac{1}{1-\beta}\pi_C \geq \pi_D + \frac{\beta}{1-\beta}\left(\frac{V}{4}\right) \tag{5}$$

which can be written as

$$\frac{1}{1-\beta}\left(\frac{V}{2} - c\right) \geq \left(\frac{c+\epsilon}{2c+\epsilon}V - c - \epsilon\right) + \frac{\beta}{1-\beta}\left(\frac{V}{4}\right). \tag{6}$$

Let $\bar{\beta}$ be the minimum discount factor to sustain collusion. Then, in the socially optimal collusion, $c = 0$ and (6) implies

$$\bar{\beta} = \frac{\frac{1}{2}V - \epsilon}{\frac{3}{4}V - \epsilon}. \tag{7}$$

Since $c = 0$, the optimal expenditure in the defection period, ϵ, is the least non-zero expenditure allowed in the contest.[3] Since $\bar{\beta}$ is decreasing in ϵ, we find that if β is not lower than $\frac{2}{3}$, then collusion with $c = 0$ can be sustained for any minimum value of expenditure allowed in the contest. On the other hand, if $c > 0$, we derive the defector's optimal expenditure, which maximizes π_D in the defection period. We find that the optimal value of ϵ is

$$\epsilon^* = \sqrt{cV} - 2c. \tag{8}$$

[3] Brookins, Ryvkin and Smyth (2021). derive $\bar{\beta}$ for the case $c = 0$ and the least non-zero expenditure allowed is 1.

Since $c < \frac{V}{4}$, ϵ^* is positive. It follows that the maximum value of π_D is

$$\pi_D^* = (\sqrt{V} - \sqrt{c})^2. \tag{9}$$

Given (5), collusion with $c > 0$ can be sustained if

$$\frac{1}{1-\beta}\left(\frac{V}{2} - c\right) \geq (\sqrt{V} - \sqrt{c})^2 + \frac{\beta}{1-\beta}\left(\frac{V}{4}\right) \tag{10}$$

which implies

$$\bar{\beta} = \frac{\frac{1}{2}V - 2\sqrt{Vc} + 2c}{\frac{3}{4}V - 2\sqrt{Vc} + c} = \frac{2(\sqrt{V} - 2\sqrt{c})}{3\sqrt{V} - 2\sqrt{c}}. \tag{11}$$

We find that $\bar{\beta}$ is strictly decreasing in c, $\lim_{c\to 0}\bar{\beta} = \frac{2}{3}$, and $\lim_{c\to\frac{V}{4}}\bar{\beta} = 0$. Therefore, given any $\beta \in (0, 1)$, there exists a level of $c \in (0, \frac{V}{4})$ such that collusion can be sustained. To achieve the socially optimal collusion, i.e., $c = 0$, it is necessary that $\beta \geq \frac{2}{3}$. If $\beta < \frac{2}{3}$, then collusion can still be supported in equilibrium, but the expenditure level will be strictly greater than zero. Given (11), we can derive the minimum expenditure that can be supported given β as

$$\bar{c} = \begin{cases} \frac{(2-3\beta)^2}{4(2-\beta)^2}V & \text{if } \beta < \frac{2}{3} \\ 0 & \text{if } \beta \geq \frac{2}{3} \end{cases}. \tag{12}$$

For example, if $V = 1000$ and $\beta = \frac{3}{5}$, then the colluded amount of investment for each player in equilibrium is between 5.1 and 250.

2.2 Winner Carryover

In this subsection, we assume the winner of the previous contest (the Incumbent) can carry over a fraction of his expenditure from the previous period and combine it with his expenditure in the current period while the other player (the Challenger) cannot. Formally, a player is in state I in period t if that player won the contest in period $t-1$ and a player is in state C in period t if the player lost the contest in period $t-1$. Since the carryover amount is proportional to the Incumbent's previous expenditure, but the Incumbent could have been the Incumbent or the Challenger last period, we index each period of the model by how many consecutive periods the Incumbent has maintained his status denoted by τ. Thus, $\tau = 0$ represents a period in which there is no incumbent, i.e., the first time the two players interact, $\tau = 1$ represents a period in which the incumbent is different from the incumbent in the previous period, and $\tau \geq 2$ represents a period in which the incumbent is repeated. Let $p_{I,\tau}$ and $p_{C,\tau}$ denote the probabilities that the Incumbent and the Challenger win in period τ, respectively. Figure 1 illustrates these probabilities and the transition between states from period τ to period $\tau + 1$.

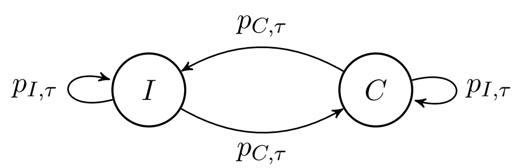


Figure 1: State-transition probabilities from period τ to period $\tau + 1$

Suppose that the Incumbent in the previous period wins the contest, so he remains the Incumbent in period τ for $\tau \geq 2$. The Bellman equations for the two players, without a role change for $\tau \geq 2$ consecutive periods, are:

$$v_I(e_{I,\tau-1}) = \max_{e_{I,\tau}} \{p_{I,\tau}V - e_{I,\tau} + \beta [p_{I,\tau}v_I(e_{I,\tau}) + p_{C,\tau}u_C(e_{C,\tau})]\} \tag{13}$$

$$v_C(e_{I,\tau-1}) = \max_{e_{C,\tau}} \{p_{C,\tau}V - e_{C,\tau} + \beta [p_{C,\tau}u_I(e_{C,\tau}) + p_{I,\tau}v_C(e_{I,\tau})]\} \tag{14}$$

where

$$p_{I,\tau} = \frac{e_{I,\tau} + \delta e_{I,\tau-1}}{e_{I,\tau} + \delta e_{I,\tau-1} + e_{C,\tau}}, \qquad p_{C,\tau} = \frac{e_{C,\tau}}{e_{I,\tau} + \delta e_{I,\tau-1} + e_{C,\tau}}, \tag{15}$$

and

$$u_I(e_{C,0}) = \max_{e_{I,1}} \{p_{I,1}V - e_{I,1} + \beta [p_{I,1}v_I(e_{I,1}) + p_{C,1}u_C(e_{C,1})]\} \tag{16}$$

$$u_C(e_{C,0}) = \max_{e_{C,1}} \{p_{C,1}V - e_{C,1} + \beta [p_{C,1}u_I(e_{C,1}) + p_{I,1}v_C(e_{I,1})]\} \tag{17}$$

where

$$p_{I,1} = \frac{e_{I,1} + \delta e_{C,0}}{e_{I,1} + \delta e_{C,0} + e_{C,1}}, \qquad p_{C,1} = \frac{e_{C,1}}{e_{I,1} + \delta e_{C,0} + e_{C,1}}. \tag{18}$$

Equations (16) and (17) are the Bellman equations for the two players when $\tau = 1$. The carryover for the new Incumbent in $\tau = 1$ is proportional to the Challenger's expenditure in $\tau = 0$, denoted by $e_{C,0}$, as shown in (18).

The first order conditions of the above Bellman equations for the Incumbent and the Challenger in period $\tau \geq 1$ are

$$\frac{\partial p_{I,\tau}}{\partial e_{I,\tau}} V + \frac{\partial p_{I,\tau}}{\partial e_{I,\tau}} \beta[v_I(e_{I,\tau}) - u_C(e_{C,\tau})] + \beta p_{I,\tau} \frac{\partial v_I(e_{I,\tau})}{\partial e_{I,\tau}} = 1 \tag{19}$$

$$\frac{\partial p_{C,\tau}}{\partial e_{C,\tau}} V + \frac{\partial p_{C,\tau}}{\partial e_{C,\tau}} \beta[u_I(e_{C,\tau}) - v_C(e_{I,\tau})] + \beta p_{C,\tau} \frac{\partial u_I(e_{C,\tau})}{\partial e_{C,\tau}} = 1 \tag{20}$$

with all of the derivative terms in (19) and (20) provided in Appendix A. While the marginal cost of expenditure appears on the right-hand side of each equality, there are three components of the marginal benefit on the left-hand side. The first term is the change in the expected prize amount due to the higher probability of winning in the current period. The second term is the expected return from being an Incumbent rather than the Challenger in the next period due to the higher probability of winning in the current period. The third term is the expected change in the value of winning the contest in the next period due to the carried over amount from the current period.

Without knowing the functional forms of u_I, u_C, v_I, or v_C in (19) and (20), it is not possible to predict the specific path that expenditures will take in this game from an arbitrary initial condition. However, we can derive the differences $v_I - u_C$ and $u_I - v_C$ in the steady state where $e_{I,\tau} = \bar{e}_I$ and $e_{C,\tau} = \bar{e}_C$. Specifically, we can write

$$v_I(\bar{e}_I) - u_C(\bar{e}_C) = u_I(\bar{e}_C) - v_C(\bar{e}_I) = \frac{[(\bar{p}_I - \bar{p}_C)V - (\bar{e}_I - \bar{e}_C)][1 + \beta(\bar{p}_I - \bar{p}_C)]}{1 - \beta(\bar{p}_I - \bar{p}_C)}. \tag{21}$$

The derivation of (21) can be found in Appendix A.

For example, given $V = 1000$ and $\beta = \frac{3}{5}$, we find that $\bar{e}_I = 174.2$ and $\bar{e}_C = 277.4$.

Comparing to the the situation where there is no carryover and each player's investment in the stage game equilibrium is $\frac{V}{4} = 250$ in every period, we find that the Incumbent invests less because the carryover from the previous period reduces the marginal benefit of the investment in the current period, while the Challenger invests more because of a possibility that $\frac{3}{5}$ of his investment in the current period will be carried over to the next period. However, if we consider the first period of a repeated contest with winner carryover, i.e., $\tau = 0$, neither players are Incumbent or Challenger in this period. It follows immediately that each player will invest more than 250 because there is no investment carried over from the previous period.

3 Experimental Design

As the previous section shows, theory does not provide clear predictions as to how an incumbency advantage will impact behavior in indefinitely repeated play contests.[4] Therefore, we rely upon controlled laboratory experiments to investigate how the ability of the winner in one period to carry over a portion of their investment to the next period affect behavior. Specifically, we implement a 2×1 between-subject experimental design. In the *No Carryover* baseline, a pair of subjects compete in a series of contests where their actions in one contest did not impact another contest's outcome. For simplicity, both here and in the experiment, we use the term period when referring to the stage-game contest and the term round when referring to the indefinitely repeated super-game. Because, there was no spillover from one period to another within a round in No Carryover, the probability that contestant i would win the prize $V = 1000$ in a period was $\frac{e_{i,t}}{e_{i,t}+e_{-i,t}}$. To help the participants understand the structure of the contest, it was described as a raffle where each contestant could buy tickets at the cost of 1 lab dollar per ticket and then one raffle ticket would be drawn to determine who received the prize that period. Given the parameter values, the numerical prediction for the No Carryover Baseline is the standard result of $e_i = \frac{V}{4} = 250$ and each player has an equal chance of winning the contest and has an

[4]While it is possible to identify a steady state equilibrium with winner carryover, that calculation ignores the possibility of players implementing grim trigger strategies to sustain collusion.

expected payoff of $\frac{V}{4} = 250$ each period. By contrast, in *Winner Carryover* the player who won the contest in the current period had an advantage in the next period. Specifically, the player who won the contest would have $\frac{3}{5}$ of the tickets he purchased in the current period automatically carried over and entered into the raffle in the next period of the round as well. Thus, in Winner Carryover the contestants were symmetric at the start of the round, but not thereafter, as was common knowledge. A session consisted of eight participants in a single treatment. Upon entering the laboratory, subjects were seated at individual computer stations and followed along as a researcher read aloud an initial set of instructions common to all treatments describing a one-shot contest.[5] Participants then completed four unpaid one-shot practice contests against the computer. Participants were informed that they would play against the computer and that the computer was programmed to purchase a random number of tickets up to 1000 in each practice contest. After the practice contests, the subjects again followed along as a researcher read aloud treatment-specific instructions. Participants were informed 1) that half of them had been assigned to the Crimson group and the other half had been assigned to the Gray group, 2) of their own group assignment, 3) that group assignments remained fixed throughout the study, and 4) that they would always be matched with a different person from the other color group each round.[6] As was explained to the participants, matching contestants each round was done using a turnpike design so that not only did no pair of contestants interact in multiple rounds, no participant's own action in one round could indirectly influence anyone the participant would meet in a subsequent round (Cooper et al. (1996)). Once the instructions had been read and clarifying questions answered, participants proceeded to complete four rounds in the assigned. At the end of each period, participants received the following feedback: who won the prize that period, their own earnings for the period, the other contestant's earnings for the period, the number of tickets they purchased, the number of tickets the other contestant purchased, any tickets carried over from the previous

[5] All instructions are provided in Appendix B. The computerized study was conducted using z-Tree (Fischbacher, 2007).

[6] The color assignment was used to avoid potential bias regarding ordering that might exist if numbered or lettered group names were used. The colors used reflect the school's mascot. It is possible that assignment to groups strengthens the participant's desire to win the contest. However, there is no reason to anticipate that the intensity of any such effect varies by treatment.

period, and their probability of having won the prize that period given the number of tickets purchased and any tickets that had been carried over. After each of the first three rounds, participants were reminded of the process used to rematch contestants. To implement the indefinite round horizon with $\beta = \frac{5}{6}$, the following procedure was used. Before the experiments were conducted, a six-sided die was rolled repeatedly until a six appeared. The number of periods in a round was equal to the number of rolls that had occurred when a six first appeared. This procedure was repeated four separate times, once for each round. To maintain consistency across sessions, the duration of rounds in all sessions was based on the same four sequences of die rolls. The actual number of periods in rounds 1 - 4 were 2, 4, 6, and 4, respectively. To allow for behavior to be observed for several periods for each pair the participants were informed of the process that was used to determine the number of periods in a round, but not the realization. Further, participants were informed that they would complete 12 periods in a round after which it would be revealed if 1) the actual number of periods was 12 or less or 2) the actual number of periods exceeded 12. If the actual number of periods in the round was 12 or less, then after the 12^{th} period the participants were informed of the actual duration of the round and all payoffs were based upon that duration. If the actual number of periods exceeded 12 then after the 12^{th} period it would be revealed that the round would continue and that it would be revealed after each subsequent period if the round would end. At the end of the study, one round was randomly selected, and subjects received their earnings for the actual period of the respective round (see Azrieli, Chambers and Healy (2020)). The study's monetary amounts were denoted in Lab Dollars, and it was common information that Lab Dollars would be converted into \$US at the rate of 100 Lab Dollars = 1 \$US. To account for the fact that half of the participants would lose money in the first period of a round and that some participants might lose money in several periods, each participant also received an endowment of 1500 Lab Dollars. The average salient earnings, including the endowment, were \$US 9.66. In addition, participants received a flat payment of 5 \$US for completing the one-hour session. The study was conducted at the University of Alabama's TIDE Lab. Data are reported from 80 participants who completed the study comprising five sessions per treatment.[7] The participants were drawn from the lab's standing pool of study volunteers who are overwhelmingly business school undergraduates. None of the participants had previously participated in any related studies.

4 Behavioral Results

Our data consist of 80 indefinitely repeated contests for both treatments and a total of 1920 individual contests. We report the analysis in three subsections. The first examines behavior between treatments and focuses on aggregate expenditure by a pair of contestants. The other subsections each discuss the behavior of contestants by role and treatment separately.

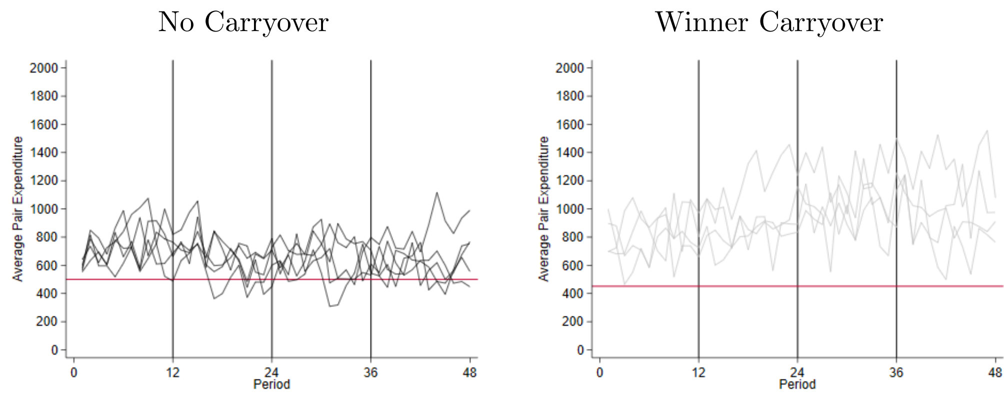
4.1 Comparing Behavior Between Treatments

Figure 2 plots the combined expenditure of both players in a contest by period. The vertical lines indicate the breaks between rounds (i.e., when subjects were re-matched and a new indefinitely repeated super-game began). The top left panel shows the combined expenditure averaged across all contestant pairs by treatment. The other two panels in Figure 2 show the combined expenditure averaged across the contestant pairs in a session for a given treatment. In this figure and all subsequent figures, we use the same color-coding (black for data from No Carryover and light gray for data from Winner Carryover) to facilitate easy comparisons between treatments.[8]

[7] In a session of the Winner Carryover treatment, a participant selected 0 every period. When questioned after the study, the participant indicated that he was satisfied receiving the endowment and was unwilling to risk leaving with anything less than that amount. Contestants matched with this individual quickly learned they could spend a trivial amount and win with certainty. For this reason an additional session was completed. While the qualitative results presented in the next section remain unchanged if the data from this session are included, we omit it from our analysis as the subject's local satiation means that the subject's incentives did not align with those of the model being tested. Thus, there was a loss of experimental control.

[8] Figure 2 does not show any strong time trends in behavior. If round and period are included in the regression analysis shown below, the qualitative results are unchanged and thus they are omitted in the paper for simplicity.

Figure 2: Average Total Contribution by a Pair of Contestants



The top left panel shows the average combined expenditure each period by treatment while the other three panels show session level total expenditure. Horizontal lines indicate the theoretical predictions of total expenditure in steady state derived in Section 2 (500 for No Carryover and 451.6 for Winner Carryover) and vertical lines indicate the start of a new indefinitely repeated game.

Figure 2 shows that total expenditure in Winner Carryover is greater than it is in No Carryover. Further, expenditures in No Carryover exceed those their predicted level. These patterns are generally borne out statistically as well. Specifically, we estimate the following regression with standard errors clustered at the session-level where the dependent variable is *TotalExpend*, i.e., the total expenditure by a pair of contestants in a period. *WinnerCO* is an indicator variable that take on the value of 1 if the observation is from the Winner Carryover treatment and is zero otherwise.[9] Because the first period differs from subsequent periods in that there can be no carryover, the data from period 1 is excluded in this analysis and considered separately below.

$$Total\hat{E}xpend = \beta_0 + \beta_1 WinnerCO \tag{22}$$

The results of this regression are presented in Table 1. The specification estimated with data from all rounds is presented in the first column of the table while the second column relies only on data from the last round after subjects have gained experience.

The Winner Carryover treatment leads to greater total expenditure than the baseline

[9]The analysis also controlled for period and round effects.

Table 1: Regression Analysis of Treatment Effects on Total Expenditure

Coefficient	(1)	(2)
Constant (β_0)	668.63***	644.41***
	(32.41)	(52.28)
Winner Carryover (β_1)	329.02***	348.88***
	(78.89)	(99.74)
R^2	0.14	0.14
Observations	1760	440
Two-sided p-value		
$H_0 : \beta_0 = 500$	< 0.001	0.006

The dependent variable for each specification is the total expenditure for each subject pair. Specification (1) includes data from period 2 or later of all rounds while specification (2) only includes data from period 2 or later of the final round. The results are based on linear regression with random effects for each session. Standard errors are in parenthesis and are clustered at the session level. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

which is evident from the positive and highly significant value of β_1 for both specifications. For the No Carryover baseline, a pair of contestants are expected to spend 500. The observed expenditure is captured by the β_0 term, which is significantly greater than 500 (p-value < 0.001 in column 1 and p-value $= 0.005$ in column 2).

Before moving to treatment level analysis, we compare period 1 behavior across treatments. Figure 3 provides box plots for first period expenditure by a single contestant between treatments. In all of the contests shown in Figure 3, the contest's outcome is based solely on the expenditures made during that period. No contestant has positive carryover from a previous period. Consistent with the results discussed above, the box plots for period 1 expenditures show that expenditures are substantially higher for the Winner Carryover treatment than for No Carryover. This behavior is intuitive given the additional advantage that winning the first period conveys in the Winner Carryover treatment.

Figure 3: Box Plots for Period 1 Expenditure in Both Treatments

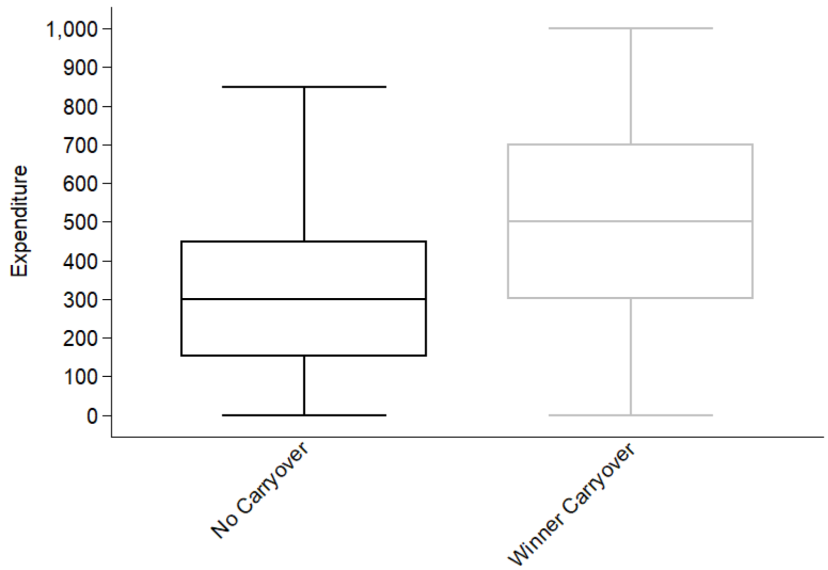


Table 2 provides regression analysis of total expenditure by a pair of contestants in period 1 both for all rounds and for the final round, similar to that reported in Table 1 for subsequent periods. Winner Carryover leads to higher expenditure than No Carryover as evidenced by the positive and significant coefficient for WinnerCO (p-value < 0.001 for both columns). As a final point, we note that expenditures exceed the theoretical prediction in period 1 for all rounds and the final round in the No Carryover treatment (p-values < 0.001 and$= 0.016$, respectively).

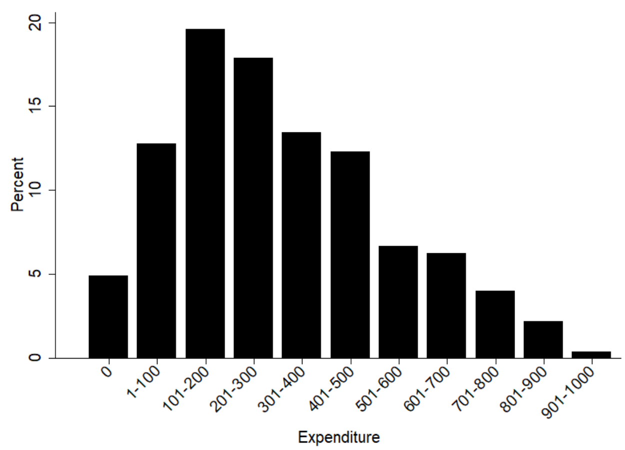
Table 2: Regression Analysis of Treatment Effects on Total Expenditure in Initial Period

Coefficient	(1)	(2)
Constant (β_0)	645.69***	615.95***
	(29.52)	(48.87)
Winner Carryover (β_1)	407.75***	606.30***
	(40.01)	(63.84)
R^2	0.26	0.42
Observations	160	40
Two-sided p-value		
$H_0 : \beta_0 = 500$	< 0.001	0.017

The dependent variable for each specification is the total expenditure for each subject pair. Specification (1) includes data from the first period of all rounds while specification (2) only includes data from the first period of the final round. The results are based on linear regression with random effects for each session. Standard errors are in parenthesis and are clustered at the session level. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

4.2 Behavior in No Carryover

Figure 4: Histogram of Individual Expenditures in No Carryover Treatment



Bins include all expenditures greater than or equal to the the lower bound and less than the upper bound with the exception of the last bin that includes expenditures equal to 1000. For consistency with other treatments, data from the first period of an indefinitely repeated game is omitted.

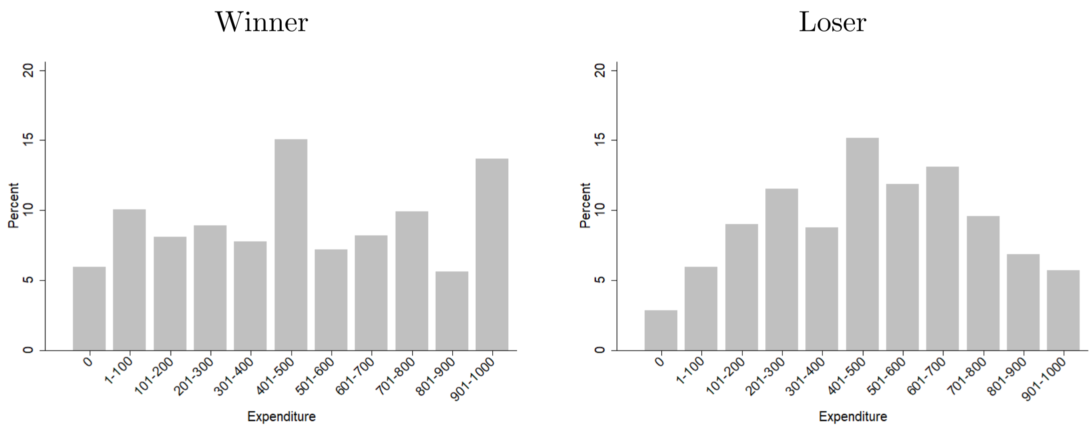
While the main purpose of the No Carryover is to serve as a basis for comparison with the Carryover treatment, we analyze it separately for completeness. Figure 4 shows the distribution of individual expenditures. For consistency with the subsequent analysis of the other treatment, this figure excludes data from the first period of the indefinitely repeated contest. There is overbidding with an overall average expenditure that is 133% of the stage-game prediction, but this is not as great as what is typically observed in one-shot Tullock contests (see Dechenaux, Kovenock and Sheremeta (2015)).[10] In this regard, our findings are consistent with Brookins, Ryvkin and Smyth (2021), who also found the repeated play reduced expenditure relative to one-shot behavior. However, Brookins, Ryvkin and Smyth (2021) found that repeated play with either a finite horizon or an indefinite horizon with the same expected duration both yield behavior close to the stage-game prediction, whereas we still observe sizeable overbidding.

4.3 Behavior in Winner Carryover

The analysis excludes data from the first period of the indefinitely repeated contest as there is no Incumbent and there can be no carryover in that period. Figure 5 plots the distribution of expenditures in the Winner Carryover treatment separately for Incumbents and Challengers. Expenditures by both Incumbents and Challengers are much more dispersed than expenditures in the baseline. It also appears that Challengers are more likely to make extremely large or extremely small expenditures than are Incumbents.

[10] Even in the final round, the average stage game bid is 128% of the predicted level.

Figure 5: Histogram of Expenditure by Incumbents and Challengers in Winner Carryover

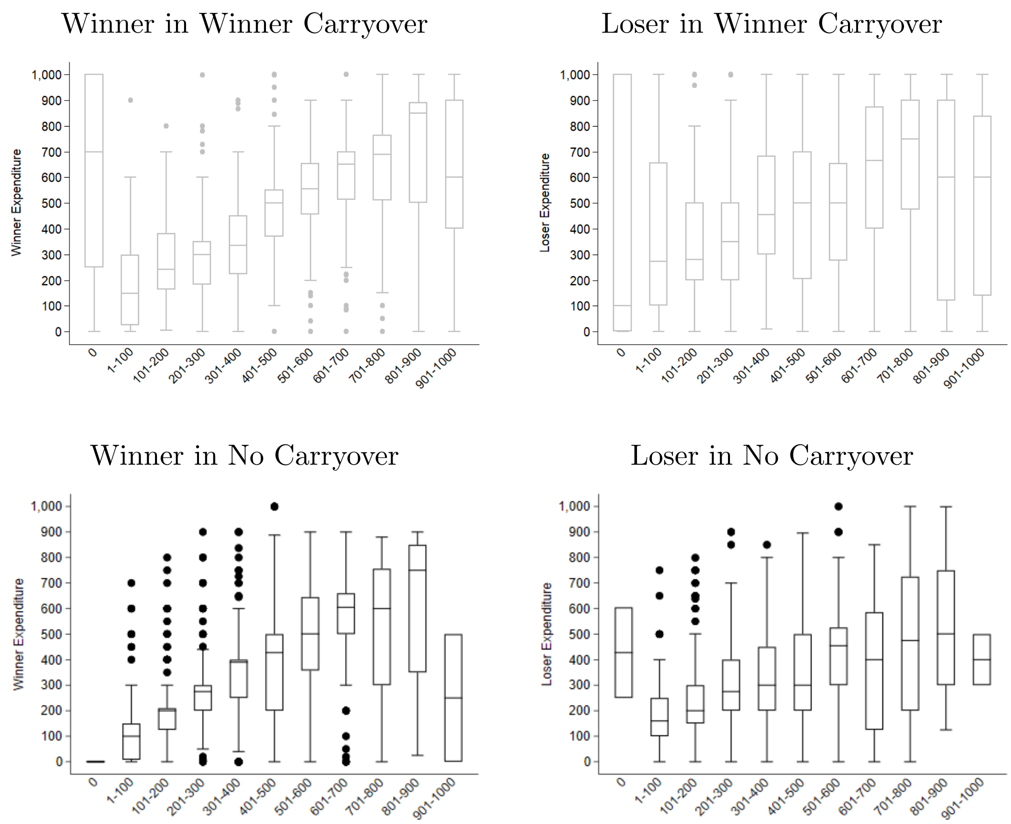


Bins include all expenditures greater than or equal to the the lower bound and less than the upper bound with the exception of the last bin that includes expenditures equal to 1000. Data from the first period of an indefinitely repeated game is omitted.

To examine how behavior in the Winner Carryover treatment depends on the amount being carried over by the Incumbent, we provide box plots of expenditures by role. The x-axis for the plots of both Incumbents and Challengers is the amount the Incumbent spent in the previous period (and thus carryover is $\delta = \frac{3}{5}$ of this amount. These plots are shown in the top row of Figure 6. From the figure it is clear that both Incumbents and Challengers spend more when the Incumbent's carryover is larger. However, it is not clear if the contestants are reacting to the carryover per se or simply reacting to the behavior in the previous period. To address this, in the bottom row of Figure 6, we plot the data from the No Carryover treatment as if it had been from the Winner Carryover treatment. That is, we evaluate Incumbent and Challenger bids conditional on the Incumbent's expenditure in the previous period. From the figure, it is clear that both Incumbents and Challengers spend more in the baseline when the Incumbent spent more in the previous period, just as in the Winner Carryover treatment. However, Incumbents in Winner Carryover do appear to spend more than Incumbents in No Carryover, conditional on their prior expenditure. Additionally, Challengers in Winner Carryover appear to be somewhat more responsive to the Incumbent's previous expenditure in Winner Carryover than are challengers in No

Carryover.

Figure 6: Box Plots of Expenditure by Role Contingent on Incumbent's Previous Expenditure



For contestants in Winner Carryover (the top portion of the figure), Incumbent's carryover in the current contest is $\delta = \frac{3}{5}$ of the Incumbent's expenditure in the previous contest. For the sake of comparison, data from No Carryover (the lower portion of the figure) is presented in the same format although there is no actual carryover for the Incumbent and thus the Incumbent's expenditure in the previous contest has no bearing on the outcome of the current contest. Data from the first period of an indefinitely repeated game is omitted.

To statistically evaluate the relationship between carryover and expenditure, we rely upon the regression analysis reported in Table 3. The variable *Incumbent* takes the value 1 if the expenditures was made by the contestant who won the previous period and is zero otherwise. *Carryover* is $\frac{3}{5}$ of the Incumbent's expenditure in the previous period and thus is carryover for those in the Winner Carryover treatment and reflects what carryover would have been had the same carryover rules applied to those in the No Carryover baseline.

Table 3: Regression Analysis of Individual Expenditure in Winner Carryover

Coefficient	(1)	(2)	(3)	(4)
Constant (β_0)	244.59***	236.42***	241.65***	228.51***
	(42.52)	(27.77)	(39.60)	(26.58)
Baseline (β_1)			-45.94	41.69
			(44.71)	(42.22)
Incumbent (β_2)	-14.38	19.50	-14.38	19.50
	(10.93)	(29.00)	(10.30)	(27.36)
Baseline × Incumbent (β_3)			-61.32**	-148.88**
			(25.03)	(58.30)
Carryover (β_4)	0.56***	0.53***	0.57***	0.56***
	(0.13)	(0.17)	(0.12)	(0.16)
Carryover × Incumbent (β_5)	0.17***	0.08	0.17***	0.08
	(0.05)	(0.11)	(0.05)	(0.10)
Carryover × Baseline (β_6)			-0.02	-0.42*
			(0.15)	(0.24)
Carryover × Baseline × Incumbent (β_7)			0.24	0.69**
			(0.15)	(0.27)
R^2	0.22	0.18	0.22	0.20
Observations	1760	440	3520	880
Two-sided p-value				
$H_0 : \beta_4 + \beta_5 = 0$	< 0.001	< 0.001	< 0.001	< 0.001
$H_0 : \beta_1 + \beta_3 = 0$			0.010	0.054
$H_0 : \beta_6 + \beta_7 = 0$			0.192	0.180

The dependent variable for each specification is the expenditure of each subject. Specifications (1) and (3) include data from period 2 or later in all rounds while specifications (2) and (4) only include data from periods 2 or later in the final round. Specifications (1) and (2) only include data from the Winner Carryover treatment whereas specifications (3) and (4) include data from both Winner Carryover and No Carryover. For data from the No Carryover treatment, the variable carryover equals three-fifths of the Incumbent's expenditure in the previous period, just as it does for data in the Winner Carryover treatment. The results are based on linear regression with random effects for each session. Standard errors are in parenthesis and are clustered at the session level. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Focusing on specifications (1) and (2) in Table 3, the insignificant coefficient on *Incumbent* suggests Incumbents do not behave differently than challengers when carryover is negligible (zero). Challengers respond positively to the Incumbent's carryover as β_4 is positive and significant. Incumbent's also make larger expenditures when they have greater carryover, as evidence by the test of $\beta_4 + \beta_5 = 0$ in the lower portion of the table. However, there is mixed evidence of whether Incumbents and Challengers respond differently to the Incumbent's carryover. While Incumbents are significantly more responsive overall, the difference is small and insignificant in the final round (β_5 is positive and significant in specification 1 but not significant in specification 2).

We now turn to compare behavior between Winner Carryover and No Carryover using specifications (3) and (4) in Table 3. The lack of significance on β_1 indicates that when carryover is small (zero), Challengers behave similarly in both treatments. For Incumbents, the difference between treatments when carryover is small is captured by $\beta_1 + \beta_3$, which is significant in both specifications indicating that Incumbents spend more after a period in which they spent a small amount in the Winner Carryover treatment. β_6 captures any differential response by Challengers to carryover between treatments. This term is insignificant over all rounds and only marginally significant in the final round. This suggests that Challengers in Winner Carryover are really responding more to the Incumbent's expenditure in the previous period than the carryover resulting from that expenditure. Any differential in the Incumbent's response to the Incumbent's previous expenditure is captured by $\beta_6 + \beta_7$, which, as shown in the lower portion of Table 3, is not significantly different from zero. Thus, the response to carryover observed in specifications (1) and (2) is not due to the carryover amount per se. Still, this result combined with the significance of $\beta_1 + \beta_3$ indicates that Winner Carryover encourages Incumbents to increase their expenditures by approximately 100 ($\approx |\beta_1 + \beta_3|$) as compared to the No Carryover baseline.

5 Conclusion

Because many naturally occurring situations, like political campaigns, can be modeled as contests, an extensive theoretical and behavioral literature has developed on this topic.

Scholars have recently begun considering the effects of repeated interactions in contests, mimicking the growing interest in repeated play games more generally. In this paper, we consider indefinitely repeated play Tullock contests with dynamic linkages between stage games. Specifically, we consider the effects of the winner in one period being able to carry forward a portion of their expenditure to the next period as such an incumbency advantage is likely to accrue in settings like political campaigns.

In a series of controlled laboratory experiments, we find that winner carryover substantially increases total expenditure in comparison to the indefinitely repeated game with no carryover. Further, the more the incumbent carries over, the more both the incumbent and the challenger spend. However, a similar pattern is observed when carryover is not possible, suggesting it is the past play that contestants are reacting to rather than the amount of carryover per se. This does not mean that there is no impact of carryover; winner carryover shifts the level of incumbent expenditure. This suggests that incumbents are willing to pay to retain their role as the incumbent beyond the strategic advantage that it provides. Such a pattern is consistent with popular press accounts of large spending by political campaigns.

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Appendix A. Theoretical Derivations

The derivatives are

$$\frac{\partial p_{I,1}}{\partial e_{I,1}} = \frac{e_{C,1}}{(e_{I,1} + \delta e_{C,\tau} + e_{C,1})^2}, \qquad \frac{\partial p_{C,1}}{\partial e_{C,1}} = \frac{e_{I,1} + \delta e_{C,\tau}}{(e_{I,1} + \delta e_{C,\tau} + e_{C,1})^2}, \tag{23}$$

$$\frac{\partial p_{I,\tau}}{\partial e_{I,\tau}} = \frac{e_{C,\tau}}{(e_{I,\tau} + \delta e_{I,\tau-1} + e_{C,\tau})^2}, \qquad \frac{\partial p_{C,\tau}}{\partial e_{C,\tau}} = \frac{e_{I,\tau} + \delta e_{I,\tau-1}}{(e_{I,\tau} + \delta e_{I,\tau-1} + e_{C,\tau})^2}, \tag{24}$$

for $\tau \geq 2$, and

$$\begin{aligned} \frac{\partial u_I(e_{C,\tau})}{\partial e_{C,\tau}} &= \frac{\partial p_{I,1}}{\partial e_{C,\tau}} \left\{ V + \beta[v_I(e_{I,1}) - u_C(e_{C,1})] \right\} \\ &= \frac{\delta e_{C,1}}{(e_{I,1} + \delta e_{C,\tau} + e_{C,1})^2} \left\{ V + \beta[v_I(e_{I,1}) - u_C(e_{C,1})] \right\}, \end{aligned} \tag{25}$$

$$\begin{aligned} \frac{\partial v_I(e_{I,\tau})}{\partial e_{I,\tau}} &= \frac{\partial p_{I,\tau+1}}{\partial e_{I,\tau}} \left\{ V + \beta[v_I(e_{I,\tau+1}) - u_C(e_{C,\tau+1})] \right\} \\ &= \frac{\delta e_{C,\tau+1}}{(e_{I,\tau+1} + \delta e_{I,\tau} + e_{C,\tau+1})^2} \left\{ V + \beta[v_I(e_{I,\tau+1}) - u_C(e_{C,\tau+1})] \right\}, \end{aligned} \tag{26}$$

for $\tau \geq 1$. In steady state $e_{i,t} = \bar{e}_i$, so that $p_{i,t} = \bar{p}_i$ and, given the Bellman equations in (16), (17), (13), and (14), we find that

$$v_I(\bar{e}_I) - u_C(\bar{e}_C) = (\bar{p}_I - \bar{p}_C)V - (\bar{e}_I - \bar{e}_C) + \beta \left\{ \bar{p}_I[v_I(\bar{e}_I) - v_C(\bar{e}_I)] - \bar{p}_C[u_I(\bar{e}_C) - u_C(\bar{e}_C)] \right\}, \tag{27}$$

$$u_I(\bar{e}_C) - v_C(\bar{e}_I) = (\bar{p}_I - \bar{p}_C)V - (\bar{e}_I - \bar{e}_C) + \beta \left\{ \bar{p}_I[v_I(\bar{e}_I) - v_C(\bar{e}_I)] - \bar{p}_C[u_I(\bar{e}_C) - u_C(\bar{e}_C)] \right\}, \tag{28}$$

where

$$v_I(\bar{e}_I) - v_C(\bar{e}_I) = (\bar{p}_I - \bar{p}_C)V - (\bar{e}_I - \bar{e}_C) + \beta \left\{ \bar{p}_I[v_I(\bar{e}_I) - v_C(\bar{e}_I)] - \bar{p}_C[u_I(\bar{e}_C) - u_C(\bar{e}_C)] \right\}, \tag{29}$$

$$u_I(\bar{e}_C) - u_C(\bar{e}_C) = (\bar{p}_I - \bar{p}_C)V - (\bar{e}_I - \bar{e}_C) + \beta \left\{ \bar{p}_I[v_I(\bar{e}_I) - v_C(\bar{e}_I)] - \bar{p}_C[u_I(\bar{e}_C) - u_C(\bar{e}_C)] \right\}. \tag{30}$$

Therefore,

$$v_I(\bar{e}_I) - v_C(\bar{e}_I) = u_I(\bar{e}_C) - u_C(\bar{e}_C) = \frac{(\bar{p}_I - \bar{p}_C)V - (\bar{e}_I - \bar{e}_C)}{1 - \beta(\bar{p}_I - \bar{p}_C)}. \tag{31}$$

and

$$v_I(\bar{e}_I) - u_C(\bar{e}_C) = u_I(\bar{e}_C) - v_C(\bar{e}_I) = \frac{[(\bar{p}_I - \bar{p}_C)V - (\bar{e}_I - \bar{e}_C)][1 + \beta(\bar{p}_I - \bar{p}_C)]}{1 - \beta(\bar{p}_I - \bar{p}_C)}. \tag{32}$$

Appendix B. Instructions for Experiment

All subjects observed the instructions for Part 1 and then participated in four unpaid practice periods involving standard one-shot Tullock contests played against the computer. Next, subjects read treatment-specific instructions for Part 2 of the study. Note, terms in [ ] next to section headings were not shown to the subjects. They are provided to distinguish in which treatment the instructions were shown.

Part 1

This is a study on economic decision making. You will be paid at the end of the study based upon the decisions you and others make in this study, so it is important that you understand these instructions fully. If you have a question at any point please raise your hand. Also, please make sure you have turned off and put away all personal electronic devices at this time.

In this study you will participate in several series of raffles. This set of instructions will first explain how a basic raffle works. Then you will have the opportunity to go through four practice raffles. The practice raffles will not impact your payment in any way; rather, the practice raffles are meant to help you understand how a basic raffle works. After you complete the practice raffles, you will then read instructions describing the slightly more complicated raffles in which you will participate during the main part of the study.

There are 8 people in your group equally split into two sub-groups: Crimson and Gray. Color assignment is random and everyone retains the same color throughout the study.

Your color is (Crimson/White).

How Raffles Work

The basic raffle works as follows. First, you and a contestant from the other color group each privately decide how many tickets you want to buy. Each ticket you buy costs you 1 Lab Dollar. You can buy any whole number of tickets from 0 to 1000 in a raffle. Each ticket the other contestant buys costs that person 1 Lab Dollar. One (and only one) raffle ticket is drawn at random by the computer. If the ticket that is drawn belongs to you, then you receive a prize of 1000 Lab Dollars and the other contestant receives 0 Lab Dollars. If the ticket that is drawn does not belong to you, then you receive 0 Lab Dollars and the other contestant receives 1000 Lab Dollars.

For simplicity, let's call the number of tickets the Crimson contestant buys CrimsonT and call the number of tickets the Gray contestant buys GrayT. Therefore,

- If your ticket is drawn you earn 1000 - # Tickets.
- If your ticket is not drawn you earn 0 - # Tickets.
- The probability Crimson receives the prize = CrimsonT / (CrimsonT + GrayT).
- The probability Gray receives the prize = GrayT / (CrimsonT + GrayT).

If neither you nor the other contestant buys any tickets, there is a 50 percent chance that you will receive the prize and a 50 percent chance the other contestant will receive the prize.

You will now go through four unpaid practice raffles. During the practice raffles the computer will serve as the other participant. The computer is programmed to buy a random number of tickets.

Part 2

Rounds of Raffles

In the main portion of the study you will complete four sequences of raffles. A sequence of raffles is referred to as a round. A round consists of several periods and during each period you will participate in a raffle like the practice raffles you just completed, but now the other contestant will be another person in this study.

After all contestants have recorded their decisions about how many raffle tickets to buy in a period, the computer will randomly draw one raffle ticket. You will then see 1) if you received the prize or not and 2) how many tickets the other contestant purchased and 3) how many tickets you purchased that period.

How much you earn in a round is simply the sum of how much you earned each period in the round. That is, every period there is a prize of 1000 Lab Dollars and every period you pay 1 Lab Dollar for every raffle ticket you buy. If you buy raffle tickets but are not awarded a prize for the period, your profit for that period will be negative.

Number of Periods in a Round

The number of periods in a round was predetermined by the researcher using a random process before the study began. To determine if the round will continue for another period, a regular 6-sided die was rolled. If a 6 was rolled the round would end. Otherwise the round keeps going. So from your perspective at any point there is a 5/6 chance that the round continues for at least one more period. There is a 5/6 x 5/6 chance it continues for at least two more periods, and so on.

Although the number of periods in a round was determined in advance by a random process, the number of periods in a round will not be revealed to you until after the round has ended. Instead, you will make decisions for at least 12 periods in each round. If a six was rolled after one of the first 12 periods then you will only complete 12 periods and we will only calculate your earnings for the round up until the point that the first 6 was rolled. That is, the round official ended once a six was rolled. But if it turns out that no six was rolled in the first 12 die rolls then the round will continue until a six is rolled. This means that the round could last 13, 14, 15 periods (or more) and you would have to make as many decisions as there are periods in the round. Because of this process, it is always in your best interest to behave as if the current period counts towards your payoff and that there is a 5/6 chance that there will be another period that also counts towards your payoff.

Let's look at an example. Suppose the die rolls for each period were as shown in the table below. You would go through 12 periods in the round and then it would be revealed that the round actually ended after period 5. Your payoff for the round would only be the sum of what you earned in periods 1 through 5 since the first 6 was rolled after period 5.

Period	1	2	3	4	5	6	7	8	9	10	11	12	13
Roll	3	4	1	4	6	4	5	2	6	1	4	2	

Now suppose that instead the die rolls were as shown in the following table.

Period	1	2	3	4	5	6	7	8	9	10	11	12	13
Roll	2	3	5	4	1	1	3	1	2	5	2	2	5

You would complete period 12 and it would be revealed that no 6 had been rolled. Therefore the round would continue to period 13. Since a 5 was rolled after period 13 the round would continue to period 14. This would continue until a 6 was rolled

The Other Contestant

As we indicated before, the 8 people in your group were randomly split into two subgroups: Crimson and Gray. Your color is (Crimson/ White).

Each round you will be matched with a different person from the other color. This matching is done in a particular way so that you will never interact with the same person for more than one round. Further, once you interact with someone that person will never interact with anyone that is going to interact with someone who will then interact with you. This means that nothing you do in one round can ever influence how someone else might interact with you in a future round.

Carryover [only visible for the Winner Carryover treatment]

Each period, the contestant who received the prize gets to carry over 3/5 (or 60 percent) of their raffle tickets to the next period at no additional cost. As an example, if the Crimson contestant buys 200 tickets in period 4 and receives the prize that period, then Crimson will get to carry over (3/5) x 200 = 120 tickets into period 5. Or if Gray buys 80 tickets in period 7 and receives the prize in period 7, Gray will carry over (3/5) x 82 = 49.2, which rounds to 49 tickets, into period 8. The contestant that does not receive the prize does not carry over any tickets.

Tickets that are carried over to a period are added to the raffle tickets purchased that period before the raffle is conducted. Notice that the carryover is only on tickets the contestant that received the prize bought in the previous period. The number of tickets carried over to one period has no impact on the number of tickets carried over to a subsequent period. Further, tickets are not carried over from one round to the next.

The person who did not receive the prize does not get to carry over any tickets.

For simplicity, let's call the number of tickets the Crimson contestant carries over to the next period after Crimson receives the prize CrimsonCO. And let's call the number of tickets the Gray contestant carries over to the next period after Gray receives the prize GrayCO.

If Crimson received the prize in the previous period then

- The probability Crimson receives the prize = (CrimsonT + CrimsonCO) / (CrimsonT + CrimsonCO + GrayT).
- The probability Gray receives the prize = GrayT / (CrimsonT + CrimsonCO + GrayT).

If Gray received the prize in the previous period then

- The probability Crimson receives the prize = CrimsonT / (CrimsonT + GrayT + GrayCO).
- The probability Gray receives the prize = (GrayT + GrayCO) / (CrimsonT + GrayT + GrayCO).

Your Payment

After the study is complete, one round will be randomly selected and used to calculate your payment. Your earnings from the randomly selected round will be converted to US dollars at the rate 100 Lab Dollars = 1 US Dollar.

You will also receive a 1500 Lab Dollar endowment. If your earnings are positive in the randomly selected round, these will be added to your endowment. But if you have losses in the randomly selected round these will be deducted from your endowment. You should note that this endowment is in addition to the 5 dollar participation payment you are receiving for this study.

If no one has any questions, then we will begin.