JENA ECONOMIC RESEARCH PAPERS

2012 – 020

Contests with Incumbency Advantages: An Experiment Investigation of the Effect of Limits on Spending Behavior and Outcome

by

Hironori Otsubo

www.jenecon.de

ISSN 1864-7057

The JENA ECONOMIC RESEARCH PAPERS is a joint publication of the Friedrich Schiller University and the Max Planck Institute of Economics, Jena, Germany. For editorial correspondence please contact markus.pasche@uni-jena.de.

Impressum:

Friedrich Schiller University Jena
Carl-Zeiss-Str. 3
D-07743 Jena
www.uni-jena.de

Max Planck Institute of Economics
Kahlaische Str. 10
D-07745 Jena
www.econ.mpg.de

Contests with Incumbency Advantages: An Experiment Investigation of the Effect of Limits on Spending Behavior and Outcome

Hironori Otsubo*

Faculty of Economics, Soka University

1-236 Tangi-cho, Hachioji-shi, Tokyo

192-8577 Japan

May 5, 2012

Abstract

This paper experimentally investigates the effect of limits on campaign spending and outcome in an electoral contest where two candidates, an incumbent and a challenger, compete for office in terms of the amount of campaign expenditure. The candidates are asymmetric only in that the incumbent wins the contest in case of a tie. Theory predicts that in the presence of such asymmetry spending limits put the challenger at a disadvantage and tightening the limits leads to further entrenchment of the incumbent. The experimental results confirmed the theoretical predictions regarding the effect of limits on campaign spending and outcome but yielded partial support to other predictions.

Keywords: Contest; All-pay auction; Spending limit; Incumbency advantage; Experiment

JEL Classification: C72, C92, D72

*Tel.: +81 (0) 42 691 9316; E-mail: hiroecon@gmail.com

1 Introduction

There has been a long debate about whether to impose ceilings on campaign spending during elections. Proponents of such a legislation claim that limits on campaign spending prevent an unrelenting escalation in expenditure and ensure that any qualified but financially disadvantaged citizens can still exercise their rights to seek and run for public office.[1] Meanwhile, opponents argue that campaign spending limits lead to further entrenchment of incumbents because they deprive challengers of their opportunities to overcome established incumbency advantages, such as deeper political experience, greater name recognition, and easier access to campaign finance.

Whether spending limits work for or against challengers rests largely on various types of asymmetry lying between candidates. For example, they may differ in terms of effectiveness of campaign spending. Several empirical studies reported that when challengers were more effective at turning money into votes, spending limits could promote fairness and result in competition (Palda, 1994; Samuels, 2001). Meanwhile, Pastine and Pastine (2012) found the opposite results. Another type of asymmetry may arise in fundraising efficiency. If an incumbent was able to raise campaign fund more efficiently than a challenger, spending limits would undermine the incumbent's fundraising advantage (Meirowitz, 2008). Reported results inevitably varied from one research to another due to differences in their approach. An important lesson is that it is crucial to take into account what kind of asymmetry exists between candidates for assessment of the effect of spending limits on the behavior of candidates.

This paper focuses on asymmetry that kicks in when one of the candidates has some kind of incumbency advantage. Two candidates, an incumbent and a challenger, compete for office in terms of the amount of campaign spending, and whoever spends more wins the election. They are asymmetric only in that the majority of voters favors the incumbent in case of a tie. A partial list of the possible sources of this type of asymmetry includes greater name recognition, more political experience, policy commitments, and voters' status-quo bias. Thus, the challenger has

[1]For example, according to the 1992 Royal Commission on Electoral Reform and Party Financing report, spending limits "constitute a significant instrument for promoting fairness in the electoral process. They reduce the potential advantage of those with access to significant financial resources and thus help foster a reasonable balance in debate during elections. They also encourage access to the election process." See Chapter 4 of "A History of the Vote in Canada" in Resource Centre at the Elections Canada's website. URL: `http://elections.ca/home.aspx`. (Last accessed: April 16, 2012).

to outspend the incumbent to win the election whereas the incumbent only needs a tie.

This kind of unfair treatment is often seen in naturally occurring contests in which the sole winner must be determined. In these contests, ties are broken in favor of one contestant over the others and thereby result in uneven outcomes. One example is corruption in government procurement (Lien, 1990). Suppose that two firms compete over a contract through bribery of a government official who prefers one firm to the other. Then, the official's favored firm can still obtain a contract by giving the same amount of bribes to the official as the other firm. Another example is weightlifting at the Olympic games, in which ties are broken in favor of the lifter whose weight is lighter (Szech, 2011).

The main goal of this paper is to investigate the effect of spending limits on campaign expenditure and outcome in the presence of asymmetry in question. An electoral contest is modeled as a two-person all-pay auction with complete information, discrete strategy space, and common minimum and maximum spending levels.[2] Equilibrium analysis shows that there exists a unique equilibrium in mixed strategies. Under equilibrium play, the incumbent spends and wins more in expectation than the challenger, and a decrease in the common spending limit lowers not only the expected expenditure levels of both candidates but also the challenger's chance of winning. The model demonstrates that spending limits put the challenger at a disadvantage, and that tightening the limits gets her position even worse.

The approach undertaken to test the accuracy of theoretical predictions for actual behavior is experimental (Davis and Holt, 1993; Friedman and Sunder, 1994; Kagel and Roth, 1995). By and large, the opportunities are severely limited for examining the behavioral relevance of theoretical predictions derived from highly stylized models with using field data which may have been collected for other pur-

[2]Many economic, social, and political contests can be formulated under the framework of all-pay auction. A key feature of this framework is the irrevocability of resources spent to get ahead of rivals; each contestant forfeits her resources, regardless of whether or not she wins the contest. A partial list of examples with this feature entails lobbying and influence seeking activities (Hillman and Samet, 1987), competitions for monopoly positions (Ellingsen, 1991), electoral competitions (Snyder, 1989), and rationing by waiting in line (Holt and Sherman, 1982). The theoretical literature has branched off into various directions (Hillman and Samet, 1987; Hillman and Riley, 1989; Baye et al., 1993; Amann and Leininger, 1996; Baye et al., 1996; Che and Gale, 1996; Barut and Kovenock, 1998; Che and Gale, 1998; Clark and Riis, 1998; Siegel, 2009). For a recent illuminating review of the literature, see Konrad (2009).

poses. The experimental approach allows for full control over the nature and degree of incumbency advantage, number of players, value of the prize, minimum and maximum expenditure levels, and richness of feedback information. For the purpose of the current paper, this approach is a more convincing source of data than any other empirical methods.

This work adds to a growing literature that uses laboratory experiments to examine theoretical implications of all-pay auction models (Davis and Reiley, 1998; Potters et al., 1998; Rapoport and Amaldoss, 2000; Amaldoss and Jain, 2002; Barut et al., 2002; Rapoport and Amaldoss, 2004; Gneezy and Smorodinsky, 2006; Noussair and Silver, 2006; Sacco and Schmutzler, 2008; Hörisch and Kirchkamp, 2010; Lugovskyy et al., 2010; Faravelli and Stanca, 2011). There were no studies that experimentally addressed the relationship between spending limits and spending behavior, nor were there experimental studies that explored the role of asymmetry due to incumbency advantage. The following four papers are of most relevant to this work in that they assumed discrete strategy space so that ties could take place. Potters et al. (1998) compared behavior in Tullock's rent-seeking games and in the two-person all-pay auctions that were rigorously analyzed by Bouckaert et al. (1992) and Schep (1994).[3] Their model assumes no spending limits and a symmetric tie-breaking rule by which ties are broken between the highest bidders with equal probability.[4] Rapoport and Amaldoss (2000) and Amaldoss and Jain (2002) studied two-person all-pay auctions with symmetric spending limits where neither player wins in case of a tie.[5] The value of a prize was assumed to be symmetric in the former study and asymmetric in the later.[6] In Rapoport and Amaldoss (2004), they extended their two-person all-pay auction games into the n-person games. Common to these studies was the finding that spending behavior was consistent with

[3]All equilibria of their model were characterized by Bouckaert et al. (1992), and the proof of uniqueness was provided by Schep (1994). See Baye et al. (1994) for related discussion.

[4]Theoretically, there are multiple mixed-strategy equilibria for some parameter values. Potters et al. (1998) circumvented the problem of multiplicity of equilibria by carefully designing their experiment so that there exists the unique mixed-strategy equilibrium.

[5]Cohen and Sela (2007) rigorously analyzed two-person all-pay auctions in which there is a positive probability that neither wins the prize in case of a tie.

[6]Later, Dechenaux et al. (2003, 2006) proved that the all-pay auctions analyzed in Rapoport and Amaldoss (2000) and Amaldoss and Jain (2002) possessed both symmetric and asymmetric mixed-strategy equilibria under some parameterizations. Although their experimental results were confounded by the multiplicity of equilibria, Rapoport and Amaldoss (2008) concluded that the data collected in Rapoport and Amaldoss (2000) yielded no support to the asymmetric equilibria.

equilibrium play on the aggregate level.

The paper proceeds as follows. Section 2 formally presents the model, derives the equilibrium, and discusses its implications. Section 3 presents research hypotheses and the experimental design. Section 4 summarizes main results. Section 5 concludes.

2 Theory

2.1 Model

There are two risk-neutral candidates, an incumbent and a challenger, indexed by i and c, respectively. Hereafter, $j \in \{i, c\}$ is used to refer to a generic player and $-j$ the other player. They compete over a single, symmetrically valued prize r. Each candidate simultaneously chooses her level of irrevocable expenditure e_i from the common set $E = \{0, 1, \ldots, l\}$, where l denotes a common spending limit. In order to be considered for winning the prize, each candidate has to spend at least m. Thus, the expenditure level of m can be thought as a minimum requirement for participation in the contest.[7] Hereafter, the parameters l, m, and r are assumed to integer values such that $0 < m < l < r$.

When both candidates satisfy the minimum expenditure level, the incumbent wins the prize if $e_i \geq e_c$ whereas the challenger wins the prize if $e_c > e_i$. Formally, the incumbent's contest success function is:

$$f_i(e_i, e_c) = \begin{cases} 1 & \text{if } e_i \geq m \text{ and } e_i \geq e_c \\ 0 & \text{otherwise} \end{cases}$$

The challenger's contest success function is:

$$f_c(e_c, e_i) = \begin{cases} 1 & \text{if } e_c \geq m \text{ and } e_c > e_i \\ 0 & \text{otherwise} \end{cases}$$

These contest success functions exhibit asymmetry in that ties are always broken in favor of the incumbent.[8] Candidate j's preferences are represented by the expected

[7] A minimum expenditure requirement has been discussed by Hillman and Samet (1987) in the context of all-pay auctions and by Schoonbeek and Kooreman (1997) in the context of Tullock's rent-seeking contests.

[8] More general asymmetric contest success functions have already been studied in two-person all-pay auctions with complete information (Konrad, 2002; Meirowitz, 2008) and with incomplete information (Lien, 1990; Clark and Riis, 2000; Feess et al., 2008).

value of the payoff function given by

$$u_j(e_j, e_{-j}) = r \cdot f_j(e_j, e_{-j}) - e_j.$$

2.2 Equilibrium Analysis

The game possesses no pure-strategy equilibrium because for any pure-strategy profile one of the candidates has an incentive to unilaterally deviate from her part of the strategy profile. Suppose to the contrary that there exists a pure-strategy equilibrium (e_i^*, e_c^*). First, consider the case that $e_i^* = e_c^*$. Then, the challenger wants to unilaterally deviate to $e_c = \max\{m, e_i^*+1\}$ when $e_i^* = e_c^* < l$ and 0 when $e_i^* = e_c^* = l$. Next, consider the case that $e_i^* \neq e_c^*$. Then, when $e_c^* < e_i^* < l$, the challenger is better off deviating to $e_c = \max\{m, e_i^* + 1\}$. Otherwise, the incumbent is better off deviating to $e_i = \max\{m, e_c^*\}$.

In the mixed extension of the game, denote by $\sigma = (\sigma_i, \sigma_c)$ a profile of mixed strategies. σ_j is candidate j's mixed strategy, i.e., a probability distribution over E, and $\sigma_j(e)$ is the probability assigned by σ_j to a pure strategy $e \in E$. Then:

Proposition 1. *There exists a unique equilibrium in mixed strategies (MSE) $\sigma^* = (\sigma_i^*, \sigma_c^*)$ characterized by*

$$\sigma_i^*(e) = \begin{cases} 0 & \textit{if } e \in \{0, \ldots, m-1\} \\ \frac{m+1}{r} & \textit{if } e = m \\ \frac{1}{r} & \textit{if } e \in \{m+1, \ldots, l-1\} \\ 1 - \frac{l}{r} & \textit{if } e = l \end{cases} \tag{1}$$

and

$$\sigma_c^*(e) = \begin{cases} 1 - \left(\frac{l-m}{r}\right) & \textit{if } e = 0 \\ 0 & \textit{if } e \in \{1, \ldots, m\} \\ \frac{1}{r} & \textit{if } e \in \{m+1, \ldots, l\} \end{cases} \tag{2}$$

with associated equilibrium payoffs $r - l$ for the incumbent and 0 *for the challenger.*

Proof. See Appendix A. □

Proposition 1 warrants three comments. First, the incumbent should always go into the contest whereas the challenger should stay out of the contest with positive probability. This implies that if both candidates adhere to equilibrium play the contest will always find a winner. Second, the incumbent's equilibrium payoff depends on the values of r and l whereas the challenger's equilibrium payoff is independent of them. Under equilibrium play, the incumbent should prefer the size of $r - l$ to be larger while the challenger should be indifferent to the size of $r - l$. Third, both candidates can assure their equilibrium payoffs by choosing their maximin strategies: $e_i = l$ for the incumbent and $e_c = 0$ for the challenger. It is worth noting that the current game belongs to a class of *unprofitable games* (Harsanyi, 1966) – games in which maximin strategies do not coincide with the unique equilibrium strategies, yet yield the same payoff as the equilibrium strategies. Several game theorists conjectured that the unprofitability of the equilibrium undermines its plausibility as a predictor (for example, Harsanyi, 1966; Aumann and Maschler, 1972).

Given the unique equilibrium in Proposition 1, it is straightforward to compute the expected expenditure of each candidate and her chances of winning the prize in equilibrium. For given l, m, and r, denote by $\mu_i^*(l, m, r)$ and $\theta_i^*(l, m, r)$ candidate j's expected expenditure and probability of winning in equilibrium, respectively. Each candidate's expected expenditure is computed as follows:

$$\begin{aligned}\mu_i^*(l, m, r) &= m\left(\frac{m+1}{r}\right) + \frac{1}{r}\sum_{e=m+1}^{l-1} e + l\left(1 - \frac{l}{r}\right) \\ &= l - \left(\frac{l(l+1) - m(m+1)}{2r}\right)\end{aligned}$$

for the incumbent and

$$\mu_c^*(l, m, r) = \frac{1}{r}\sum_{e=m+1}^{l} e = \frac{l(l+1) - m(m+1)}{2r}$$

for the challenger. Note that $\mu_c^*(l, m, r) < \frac{l}{2}$ because

$$\begin{aligned}\mu_c^*(l, m, r) &= \frac{l(l+1) - m(m+1)}{2r} \\ &= \frac{l}{2} \cdot \frac{l+1}{r} - \frac{m(m+1)}{2r} \\ &\leq \frac{l}{2} \cdot 1 - \frac{m(m+1)}{2r} \\ &< \frac{l}{2}\end{aligned}$$

Since $\mu_i^*(l, m, r) = l - \left(\frac{l(l+1)-m(m+1)}{2r}\right)$, $\mu_i^*(l, m, r) > \mu_c^*(l, m, r)$. Therefore, the incumbent spends more than the challenger in expectation.

In equilibrium, the incumbent never stays out of the contest, i.e., $\sigma_i^*(0) = 0$. Thus,

$$\theta_i^*(l,m,r) = 1 - \theta_c^*(l,m,r) - \sigma_i^*(0) \cdot \sigma_c^*(0) = 1 - \theta_c^*(l,m,r).$$

Each candidate's probability of winning is computed as follows:

$$\theta_c^*(l,m,r) = \frac{1}{r}\left(\frac{m+2}{r} + \frac{m+3}{r} + \cdots + \frac{l}{r}\right) = \frac{l(l+1) - m(m+1)}{2r^2} \tag{3}$$

for the challenger and

$$\theta_i^*(l,m,r) = 1 - \left(\frac{l(l+1) - m(m+1)}{2r^2}\right)$$

for the incumbent. It follows from $\theta_c^*(l,m,r) = \frac{\mu_c^*(l,m,r)}{r} < \frac{l}{2r}$ and $r > l$ that $\theta_c^*(l,m,r) < \frac{1}{2}$. Thus, the incumbent wins more often than the challenger in expectation.

2.3 Comparative Statics Analysis

How does a change in the spending limit influence each player's expected expenditure and probability of winning the prize? To answer this question, consider two distinct spending limits l_1 and l_2 such that $0 < l_1 < l_2$. Then,

$$\begin{aligned}
&\mu_i^*(l_2,m,r) - \mu_i^*(l_1,m,r) \\
&= l_2 - \left(\frac{l_2(l_2+1) - m(m+1)}{2r}\right) - l_1 + \left(\frac{l_1(l_1+1) - m(m+1)}{2r}\right) \\
&= \frac{l_2(2r - l_2 - 1)}{2r} + \frac{m(m+1)}{2r} - \frac{l_1(2r - l_1 - 1)}{2r} - \frac{m(m+1)}{2r} \\
&= \frac{(l_2 - l_1)(2r - l_2 - 1) - l_1(l_2 - l_1)}{2r} \\
&= \frac{(l_2 - l_1)[(r - l_2) + (r - l_1) - 1]}{2r} \\
&\geq \frac{1 \cdot 2}{2r} \\
&> 0.
\end{aligned}$$

Thus, the incumbent's expected expenditure decreases as l decreases. Similarly, $\mu_c^*(l_2,m,r) - \mu_c^*(l_1,m,r) > 0$. Therefore, the challenger's expected expenditure also decreases as l decreases.

A decrease in the spending limit decreases the challenger's probability of winning because by equation (3) $\theta_c^*(l_2, m, r) - \theta_c^*(l_1, m, r) > 0$ for $0 < l_1 < l_2$. This implies that a decrease in the spending limit increases the incumbent's probability of winning and thereby deteriorates fairness regarding the chance of winning.

3 Experimental Design

3.1 Research Hypotheses and Treatments

Given the comparative statics analysis, how well is the actual behavior of subjects consistent with the theoretical predictions? To evaluate the predictive power of the equilibrium solutions, this study employed a two-by-two factorial experimental design that set $m = 1$ and that varied the values of l and r. These two parameters took two levels each, $l \in \{8, 13\}$ and $r \in \{15, 20\}$, which resulted in a total of four treatments. They are referred to as *LL* ($l = 8$ and $r = 15$), *HL* ($l = 13$ and $r = 15$), *LH* ($l = 8$ and $r = 20$), and *HH* ($l = 13$ and $r = 20$). Table 1 outlines the theoretical predictions under equilibrium behavior. In the table $\mu_{j,t}^*$ and $\theta_{j,t}^*$ denote candidate j's (equilibrium) expected expenditure and probability of winning. Then, these predictions suggest the following two research hypotheses:

Hypothesis 1: Let $\mu_{j,t}$ denote the mean expenditure of candidates j in treatment t. For all $j \in \{i, c\}$ and $t \in \{LL, HL, LH, HH\}$,

$$\mu_{j,t} = \mu_{j,t}^*.$$

Hypothesis 2: A decrease in the spending limit

1. decreases the mean expenditures of incumbents and challengers, respectively, and

2. increases the winning rate of incumbents and decreases that of challengers.

In addition to these hypotheses pertaining to aggregate behavior, the unique mixed-strategy equilibrium makes the following very stringent hypothesis about individual behavior:

Hypothesis 3: Every subject follows equilibrium play.

This hypothesis can be rejected by a single violation of equilibrium play.

– Insert Table 1 about here –

3.2 Procedure

A total of two hundred fifty six student subjects from various fields of study at the Friedrich-Schiller University of Jena were recruited via the ORSEE software (Greiner, 2004). They were divided into eight cohorts of thirty two subjects each, two cohorts participating in each of the four treatments *LL*, *HL*, *LH*, and *HH*. A session invited only one cohort with no subject participating in more than one session. All eight sessions were conducted in the experimental laboratory of the Max Planck Institute of Economics in Jena, Germany, with thirty-two PCs connected in a network. The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007). A session lasted about 90 minutes, including reading instructions and paying subjects.

Upon arrival at the laboratory, each subject was asked to draw a marked chip from a box that determined her seating. Thirty-two subjects were seated in individual cubicles separated from one another by partitions. Any form of communication between subjects was strictly forbidden throughout the session, and questions were answered individually by the experimenter. After all subjects being seated, they were asked to read written instructions silently at their own pace. Once all of them indicated readiness for the experiment by clicking on an appropriate button on the computer screen, the experimenter read the instructions aloud so that all information became common knowledge. Then, subjects were given nine control questions designed to check their understanding of the instructions.[9]

Each session consists of sixty rounds (iterations) of the same two-person asymmetric all-pay auction. Prior to the first round, the computer randomly formed four groups of eight subjects each. Group composition remained the same so that no interaction between groups took place throughout the session. Then, for each group the computer randomly assigned four subjects to the role of the incumbent and the remaining four subjects to the role of the challenger. In order to avoid any social implications, these roles were labeled “X” and “Y ,” respectively. Subjects retained one role throughout the session. Each subject was privately informed of her role and conversion rate.

The sequence of each round was identically structured in all treatments. At the

[9] The English instructions and control questions for treatment *LL* are available in Appendix B.

beginning of a round, each subject was randomly paired with another subject in her group who was assigned the opposite role (i.e., a random matching protocol).[10] Once a round began, the computer exhibited a decision screen that displayed a list of $l + 1$ different numbers of tokens, namely, $0, 1, 2, \ldots, l - 1, l$. Each subject received an endowment of 14 points every round and was then asked to decide how many tokens to buy at the rate 1 point = 1 token. It was carefully explained in the instructions that points spent to buy tokens would be non-refunded. The instructions also presented the payoff matrix. Once every subject completed submission of her decision, a results screen informed each subject of the number of tokens she purchased, her opponent's decision, outcome and payoff (in points) for the current round, and current balance (i.e., total points she had accumulated so far).

At the end of a session, a summary screen displayed the total points subjects had accumulated and the corresponding earnings in euros. For subjects assigned to the role of X, the points were converted to euros at the rate of 97 points = €1 in treatments *LL* and *HH*, 74 points = €1 in treatment *HL*, and 120 points = €1 in treatment *LH*. For subjects assigned to the role of Y, the conversion rates were 65 points = €1 in all the treatments.

It is instructive to note two design features. First, the present experimental design allowed for repeated play. The reason was to let subjects to gain a considerable amount of experience. Past experimental studies that involved mixed-strategy equilibria have reported that the behavior of subjects converged to equilibrium play as they gained more experience (see Camerer, 2003, Chapter 3). For example, Potters et al. (1998) reported that 30 rounds of play were not enough for subjects to reach the unique equilibrium in mixed strategies that assign equal probability to each strategy. One method to induce experience is to allow subjects to play repeatedly under a fixed matching protocol. This method, however, facilitates tacit collusion between subjects. Another disadvantage of this method is that it does not retain the one-shot nature of the game. Thus, a random matching protocol was invoked that is less susceptible to tacit collusion and concurrently approximates the one-shot game.

Second, role-specific conversion rates were private information. Subjects in one role knew their own conversion rate but not the conversion rate for the other role.

[10] In general, this protocol does not rule out the possibility of the same two subjects interacting with each other in two consecutive rounds. However, it was impossible for any subject to associate the identities of other subjects with their decisions throughout the session.

With a uniform conversion rate, the final earnings would significantly differ between the two roles under equilibrium play, particularly in treatment *LH*. The use of private role-specific conversion rates was intended to minimize interpersonal payoff comparisons which may arouse subjects to maximize relative gain. The conversion rates were calibrated so that each subject, according to the equilibrium benchmark, would on average earn €13.50 without a €2.50 show-up bonus, regardless of which treatment and which role she was assigned. The mean of individual payoffs for subjects assigned to the role of X was €12.92 in treatment *LL*, €14.13 in treatment *HL*, €12.63 in treatment *LH*, and €13.34 in treatment *HH*, respectively, without a €2.50 show-up bonus. The corresponding value for subjects assigned to the role of Y was €12.77 in treatment *LL*, €12.85 in treatment *HL*, €12.98 in treatment *LH*, and €12.85 in treatment *HH*, respectively.[11]

4 Results

Prior to presenting main results, two features of the present statistical analysis warrant brief discussion. First, the analysis confines attention to the behavior in the last 30 rounds. As mentioned earlier, previous experimental literature suggests that it may take a considerable amount of experience for subjects to reach equilibrium play. Analyzing the last 30 rounds of play would give equilibrium theory its best shot in successfully predicting subjects' behavior. Second, the data comprise eight independent observations per treatment. Since subjects repeatedly interacted with each other within a group under rich information feedback, the assumption that all observations were independent does not hold. Therefore, each group constitutes one independent observation, and statistical tests are based on *group-level* measurement of the relevant variables.

4.1 Aggregate Behavior

Result 1: *The mean expenditure of incumbents was consistent with the predicted level in all treatments whereas that of challengers significantly differed from predicted in all but treatment LL.*

[11] When the experiment was conducted (November 2010), the EUR/USD currency exchange rate ranged approximately from \$1.35 to \$1.38.

Support: Table 2 summarizes the observed and predicted mean expenditures and winning rates by treatment and role. These observed values are computed across eight (independent) group mean expenditures. An eyeball inference suggests that the mean expenditures of incumbents were almost in line with the predicted values but those of challengers were not; the observed value fell short of the predicted level by about 2 tokens in treatment *HL* and by about 1 token in treatment *HH*. It always held that the mean expenditure of incumbents was higher than that of challengers.

– Insert Table 2 about here –

The null hypothesis of no difference between observed and predicted expenditures was formally tested by using a nonparametric bootstrap method (Efron and Tibshirani, 1993). In order to illustrate this method, consider the bootstrap test on the null hypothesis $\mu_{i,LL} = \mu^*_{i,LL}$. The observed data consists of eight (group-level) mean expenditures, denoted by $\mu_1, \mu_2, \ldots, \mu_8$. Let $\overline{\mu}$ denote its mean. Then, transform the original data into the translated data, $\hat{\mu}_g = \mu_g - \overline{\mu} + \mu^*_{i,LL}$, $g = 1, \ldots, 8$. Then,

(*i*) A bootstrap sample of size eight is randomly drawn from the translated data with *replacement*.

(*ii*) Compute the mean of the bootstrap sample, $\overline{\mu}_b$.

(*iii*) Repeat (*i*) and (*ii*) B times ($B = 10000$ in this study).

(*iv*) Arrange the B bootstrap sample means, $\overline{\mu}_1, \overline{\mu}_2, \ldots, \overline{\mu}_B$ in ascending order, and then compute the 2.5 and 97.5 percentiles of these values.

(*v*) Reject the null hypothesis of equality if $\overline{\mu}$ is either smaller than the 2.5th percentile or larger than the 97.5th percentile (i.e., 5% significance level). Otherwise, fail to reject the null hypothesis.

The test rejected the null hypothesis for challengers in three treatments at the 5% significance level; the mean expenditure was too low in treatments *HL* and *HH* and too high in treatment *LH*, provided that the null hypothesis was true. Therefore, Hypothesis 1 was only partially supported by the data.

The deviations are nuanced in Figure 1. It displays side by side the unique mixed-strategy equilibrium and the observed relative frequency distribution of expenditures by treatment and role. The figure shows that the equilibrium solutions fared the spending behavior of both candidates remarkably well. One exception is that challengers chose 0 (i.e., non-participation) far more frequently than predicted. The observed relative frequency of 0 was almost twice as much as what theory predicted (0.383 vs. 0.2). A close inspection of the data shows that this excess non-participation of challengers took place in all of the eight groups; their observed relative frequencies were 0.425, 0.367, 0.400, 0.308, 0.350, 0.283, 0.500, and 0.433.

– Insert Fig. 1 about here –

Result 2: *As the spending limit decreases, the mean expenditures of both incumbents and challengers significantly decreased, and the winning rate of incumbents significantly increased.*

Support: Table 2 shows that as predicted, the observed mean expenditures decreased as the spending limit decreased. This observation was formally tested by using the one-sided permutation test. The results are summarized in Table 3. The null hypothesis of no effect was soundly rejected in each of the four permutation tests (2 roles $\times$ 2 pairs of comparisons).

– Insert Table 3 about here –

Now, turn attention to the winning rates. Theory predicts that the probability of no winner is 0. The actual number of games that did not find a winner was only four out of 3840 games (0.1%) and thereby it suffices to focus only on the winning rates of incumbents.[12] Table 2 displays that as predicted, the observed winning rates of incumbents increased as the spending limit decreased. The one-sided permutation test soundly rejected the null hypothesis of no effect in each of the two permutation tests ($p < 0.05$ for both LL vs. HL and LH vs. HH). Hypothesis 2 was fully supported by the data.

4.2 Individual Behavior

Result 3: *A substantial heterogeneity was observed on the individual level.*

[12]For the last 30 rounds, there were 960 games per treatment.

Support: Figure 2 organizes the relative frequency distribution of expenditures by subject in group 1, treatment *LL*. Clearly, individual subjects exhibited a wide variety of spending patterns that defy a simple classification.[13] For example, challenger 1 quite successfully allocated her choice over the entire range of the support of the unique equilibrium whereas incumbent 3 always chose the highest expenditure level (e.g., maximin strategy).

– Insert Fig. 2 about here –

Diverse spending patterns resulted in differences in individual mean expenditure. Fig.3 displays the distribution of individual mean expenditures in ascending order by treatment and role. The horizontal line drawn in each graph represents the predicted expenditure level (see Table 1). Some subjects spent as much as predicted, and some others either underspent or overspent significantly. Particularly noteworthy is the finding that only nine of 256 subjects always played their maximin strategies; one incumbent and one challenger in treatments *LL* and *HH* each, and five incumbents in treatment *LH*. The remaining 247 subjects chose other spending levels than maximin strategies at least once.

– Insert Fig. 3 about here –

Equilibrium theory calls for each subject to generate her spending distribution that closely matches with the equilibrium probability distribution. Therefore, a single violation of equilibrium play by any subject suffices to reject Hypothesis 3. The Kolmogorov-Smirnov (K-S) test was invoked to test the hypothesis.[14] The test results are summarized in Table 4, which reports the number and proportion of subjects for whom the K-S test rejected the null hypothesis of equilibrium play at the 5% significance level. As can be seen, every role and every treatment found at least one subject whose behavior contradicted equilibrium play. Hence, Hypothesis 3 was soundly rejected.

– Insert Table 4 about here –

[13]This was true not only in other groups but also in other treatments.

[14]Under this hypothesis, subjects are assumed to be independent of one another as well as are 30 iterations of the same auction for each subject.

4.3 Models of Bounded Rationality

The previous analysis confirmed that the mean expenditure was directionally consistent with the theoretical predictions but not quantitatively. Past experimental studies suggested various factors that could cause discrepancies between observed and predicted patterns of behavior. For example, Potters et al. (1998) surmised that sometimes subjects made mistakes or were not sure of what to do. Sacco and Schmutzler (2008) conjectured that subjects did not only gain monetary payoffs but also derive utility from winning and disutility from losing.

Among possible causes of the deviations, this subsection explores whether the bounded rationality of subjects was responsible for the deviations. To this end, two models that entail bounded rationality are considered. The first model is the quantal response equilibrium model (QRE) developed by McKelvey and Palfrey (1995).[15] In this model, players do not necessarily choose the best choice with probability one. Instead, they select better choices with higher probability and worse choices with lower probability, according to a quantal response function that maps expected payoffs into choice probabilities. A player's expected payoffs from different choices are determined by beliefs about other players' choices, and beliefs must match choice probabilities in equilibrium. Following McKelvey and Palfrey (1995), consider the QRE that uses the following logistic quantal response function:

$$p_{j,\lambda}(e) = \frac{\exp(\lambda \cdot u_i(e, p_{-j,\lambda}))}{\sum_{k \in E} \exp(\lambda \cdot u_i(k, p_{-j,\lambda}))}, \tag{4}$$

where λ is an error parameter that ranges from 0 to ∞, and $p_{j,\lambda}(e)$ is candidate j's probability assigned to $e \in E$ by candidate j's mixed strategy $p_{j,\lambda}$. Note that $p_{j,\lambda}(e)$ is a function of λ. As λ goes to 0, $p_{j,\lambda}(e)$ converges to $\frac{1}{l+1}$ (uniform randomization). On the other hand, as λ approaches ∞, $p_{j,\lambda}(e)$ converges to $\sigma_j^*(e)$ (MSE play). Thus, λ describes the degree of rationality. The second model is the noisy Nash model (NNM), first introduced by McKelvey and Palfrey (1998). In this model, players adopt the Nash equilibrium play with probability γ and follow a uniform distribution over all strategies with probability $1 - \gamma$. The NNM differs from the QRE in that a

[15] Several experimental studies on contests have used the QRE in an attempt to bridge the gap between observed behavior and equilibrium play. A partial lists of examples include Anderson et al. (1998), Rapoport and Amaldoss (2004), and Gneezy and Smorodinsky (2006) in the literature of all pay auctions and Lim et al. (2010), and Sheremeta (2010) in the literature of Tullock's rent seeking games.

player makes errors but does not take into account that other players also commit errors.

Following McKelvey and Palfrey (1995, 1998), λ and γ were estimated by using maximum likelihood techniques.[16] To avoid overfitting, each of λ and γ was assumed to be the same across all treatments. The estimated values were 3.46 for λ and 0.94 for γ. Figure 4 displays side by side these two models and the observed aggregate relative frequency distribution of expenditures by treatment and role. The distributions of these two models overlapped each other almost perfectly and hardly differed from the MSE distribution depicted in Fig. 1. Table 5 shows the observed and predicted mean expenditures by treatment and role. The three solution concepts predicted almost identical mean expenditure levels. These bounded rational models may require further adjustment to provide a better fit than the MSE.

– Insert Fig. 4 about here –

– Insert Table 5 about here –

5 Conclusion

Past theoretical and empirical studies on campaign spending limits indicated that various types of asymmetry lying between candidates would determine whether or not spending limits level the playing field. This paper confines attention to asymmetry that arises in case of a tie due to some kind of incumbency advantage and experimentally examines how limiting the amount of campaign spending affects candidates' spending behavior in the presence of such asymmetry.

Three major findings are in order. First, the data supported all the qualitative predictions. As the common spending limit decreased, both candidates decreased their mean expenditures in a way that incumbents won more often than before. Thus, an decrease in the common spending limit led to further entrenchment of incumbents. Second, the quantitative predictions were partly supported by the data. The mean expenditure of challengers differed significantly from predicted in three out of the four treatments. The two bounded rational models, QRE and NNM, were introduced in an attempt to account for the deviations, but neither model fitted the

[16] MATLAB's `lsqnonlin` routine was used to numerically compute the quantal response equilibria for different values of λ.

data well. Third, overall the MSE characterized the observed behavior of subjects on the aggregate level, but not on the individual level. Subjects exhibited a wide variety of behavioral patterns; some subjects mixed their choices, some others did not at all. It was concluded that the observed aggregate behavior that differed little from MSE play emerged as an artifact of both individuals who followed MSE play and those who significantly deviated from it. This finding is reminiscent of the previous experimental studies that involve mixed-strategy equilibria (see Camerer, 2003, Chapter 3).

Caution must be exercised when applying the findings of this study to naturally occurring contests. The present model abstracts from realism in several aspects; a single symmetrically valued prize, an identical set of expenditure levels, an identical spending limit, and complete information. The practice of such simplification obviously undermines the external validity of findings. Yet, it served to promote subjects' understanding of the experimental environment and reduce noise in the data. Relaxing these assumptions is left for future research.

Acknowledgement

I am grateful to Werner Güth for his constructive comments and suggestions, and Karolin Schröter, Rico Löbel, and Miriam Schmidt for their excellent assistance in data collection. Generous financial support from the Max Planck Society is gratefully acknowledged.

References

Amann, E., Leininger, W. (1996). Asymmetric all-pay auctions with incomplete information: The two-player case. *Games and Economic Behavior* 14, 1–18.

Amaldoss, W., Jain, S. (2002). David vs. Goliath: An analysis of asymmetric mixed-strategy games and experimental eviddence. *Management Science* 48, 972–991.

Anderson, S. P., Goeree, J. K., Holt, C. A. (1998). Rent seeking with bounded rationality: An analysis of the all-pay auction. *Journal of Political Economy* 106, 828–853.

Aumann, R. J., Maschler, M. (1972). Some thoughts on the minimax principle. *Management Science* 18, 55–63.

Barut, Y., Kovenock, D. (1998). The symmetric multiple prize all-pay auction with complete information. *European Journal of Political Economy* 14, 627–644.

Barut, Y., Kovenock, D., Noussair, C. N. (2002). A comparison of multiple-unit all-pay and winner-pay auctions under incomplete information. *International Economic Review* 43, 675–708.

Baye, M. R., Kovenock, D., de Vries, C. G. (1993). Rigging the lobbying process: An applicatoin of the all-pay auction. *American Economic Review* 83, 289–294.

Baye, M. R., Kovenock, D., de Vries, C. G. (1994). The solution to the Tullock rent-seeking game when $R > 2$: mixed-strategy equilibria and mean dissipation rates. *Public Choice* 81, 363–380.

Baye, M. R., Kovenock, D., de Vries, C. G. (1996). The all-pay auction with complete information. *Economic Theory* 8, 291–305.

Bouckaert, J., Degrijse, H., de Vries, C. G. (1992). Veilingen waarbij iedereen betaalt en toch wint. *Tijdschrift voor Economie en Management* 37, 375–393.

Camerer, C. F. (2003). *Behavioral Game Theory.* Princeton, NJ: Princeton University Press.

Che, Y.-K., Gale, I. L. (1996). Expected revenue of all-pay auctions and first-price sealed-bid auctions with budget constraints. *Economic Letters* 50, 373–379.

Che, Y.-K., Gale, I. L. (1998). Caps on political lobbying. *American Economic Review* 88, 643–651.

Clark, D. J., Riis, C. (1998). Competition over more than one prize. *American Economic Review* 88, 276–289.

Clark, D. J., Riis, C. (2000). Allocation efficiency in a competitive bribery game. *Journal of Economic Behavior and Organization* 42, 109–124.

Cohen, C., Sela, A. (2007). Contests with ties. *The B.E. Journal of Theoretical Economics* 7, Article 43.

Davis, D. D., Holt, C. (1993). *Experimental Economics*. Princeton, NJ: Princeton University Press.

Davis, D. D., Reiley, R. J. (1998). Do too many cooks always spoil the stew? An experimental analysis of rent-seeking and the role of a strategic buyer. *Public Choice* 95, 89–115.

Dechenaux, E., Kovenock, D., Lugovskyy, V. (2003). A comment on "David and Goliath: An analysis on asymmetric mixed-strategy games and experimental evidence." Krannert working paper series. Working paper No.1162. Purdue University.

Dechenaux, E., Kovenock, D., Lugovskyy, V. (2006). Caps on bidding in all-pay auctions: Comments on the experiments of A. Rapoport and W. Amaldoss. *Journal of Economic Behavior and Organization* 61, 276–283.

Efron, B., Tibshirani, R. J. (1993). *An Introduction to the bootstrap*. New York, NY: Chapman and Hall.

Ellingsen, T. (1991). Strategic buyers and the social cost of monopoly. *American Economic Review* 81, 648–657.

Faravelli, M., Stanca, L. (2011). Single versus multiple prize all-pay auctions to finance public goods: An experimental analysis. *Journal of Economic Behavior and Organization* 81, 677–688.

Feess, E., Muelhlheusser, G., Walzl, M. (2008). Unfair contests. *Journal of Economics* 93, 267–291.

Fischbacher, U. (2007). z-Tree: Zurich toolbox for ready-made economic experiments. *Experimental Economics* 10, 171–178.

Friedman, D., Sunder, S. (1994). *Experimental Methods: A Primer for Economists.* Cambridge, UK: Cambridge University Press.

Gneezy, U., Smorodinsky, R. (2006). All-pay auctions–an experimental study. *Journal of Economic Behavior and Organization* 61, 255–275.

Greiner, B. (2004). The online recruitment system ORSEE 2.0–A guide for the organization of experiments in economics. Working paper, University of Cologne.

Harsanyi, J. C. (1966). A general theory of rational behavior in game situations. *Econometrica* 34, 613–634.

Hillman A. L., Samet, D. (1987). Dissipation of contestable rents by small numbers of contenders. *Public Choice* 54, 63–82.

Hillman A. L., Riley, J. G. (1989). Politically contestable rents and transfers. *Economics and Politics* 1, 17–39.

Holt, C. A., Sherman, R. (1982). Waiting-line auctions. *Journal of Political Economy* 90, 280–294.

Hörisch, H., Kirchkamp, O. (2010). Less fighting than predicted–experiments with wars of attrition and all-pay auctions. *Public Choice* 144, 347–367.

Kagel, J. H., Roth, A. (1995). *Handbook of Experimental Economics.* Princeton, NJ: Princeton University Press.

Konrad, K. (2002). Investment in the absense of property rights; the role of incumbency advantages. *European Economic Review* 46, 1521–1537.

Konrad, K. (2009). *Strategy and Dynamics in Contests.* New York: Oxford University Press.

Lien, D. (1990). Corruption and allocation efficiency. *Journal of Development Economics* 33, 153–164.

Lim, W., Matros, A., Turocy, T. L. (2010). Quantal response equilibrium in contest games: Theoretical predictions and an experimental test of the effects of group size. Working paper.

Lugovskyy, V., Puzzello, D., Tucker, S. (2010). An experimental investigation of overdissipation in the all pay auction. *European Economic Review* 54, 974–997.

McKelvey, R. D., Palfrey, T. R. (1995). Quantal response equilibria for normal form games. *Games and Economic Behaivor* 10, 6–38.

McKelvey, R. D., Palfrey, T. R. (1998). Quantal response equilibria for extensive form games. *Experimental Economics* 1, 9–41.

Meirowitz, A. (2008). Electoral contests, incumbency advantages and campaign finance. *Journal of Politics* 70, 681–699.

Nash, J. F. (1950). Equilibrium points in n-person games. *Proceedings of the National Academy of Sciences of the United States of America* 36, 48–49.

Noussair, C., Silver, J. (2006). Behavior in all-pay auctions with incomplete information. *Games and Economic Behavior* 55, 189–206.

Palda, F. (1994). Desirability and effects of campaign spending limits. *Crime, Law, and Social Change* 21, 295–317.

Pastine, I., Pastine, T. (2012). Incumbency advantage and political campaign spending limits. *Journal of Public Economics* 96, 20–32.

Potters, J., de Vries, C. G., van Winden, F. (1998). An experimental examination of rational rent-seeking. *European Journal of Political Economy* 14, 783–800.

Rapoport, A., Amaldoss, W. (2000). Mixed strategies and iterative elimination of strongly dominated strategies: An experimental investigation of States of Knowledge. *Journal of Economic Behavior and Organization* 42, 483–521.

Rapoport, A., Amaldoss, W. (2004). Mixed-strategy play in single-stage first-price all-pay auctions with symmetric players. *Journal of Economic Behavior and Organization* 54, 585–607.

Rapoport, A., Amaldoss, W. (2008). In search of experimental support for an asymmetric equilibria solution in symmetric investment games. *Journal of Economic Behavior and Organization* 67, 200–203.

Sacco, D., Schmutzler, A. (2008). All-pay auctions with negative prize externalities: Theory and experimental evidence. Working paper No. 0806. University of Zurich.

Samuels, D. (2001). Incumbents and challengers on a level playing field: Assessing the impact of campaign finance in Brazil. *Journal of Politics* 63, 569–584.

Samuelson, W., Zeckhauser, R. J. (1988). Status quo bias in decision making. *Journal of Risk and Uncertainty* 1, 7–59.

Schep, K. (1994). De all-pay veiling: Nash evenwichten in discrete ruimte voor twee agenten. MA thesis, Eramus Universiteit Rotterdam.

Schoonbeek, L., and Kooreman, P. (1997). Tullock's rent-seeking contest with a minimum expenditure requirement. *Public Choice* 93, 477–486.

Sheremeta, R. M. (2010). Contest design: An experimental investigation. *Economic Inquiry* 49(2): 573–590.

Siegel, R. (2009). All-pay contests. *Econometrica* 77, 71–92.

Snyder, J. M. (1989). Election goals and the allocation of campaign resources. *Econometrica* 57, 637–660.

Szech, N. (2011). Tie-breaks and bid-caps in all-pay auctions. Working paper, University of Bonn.

Appendix

A Proof of Proposition 1

Proof. Start with the proof of Lemma 1, which assures that in any equilibrium both candidates follow *non-degenerated* mixed strategies.

Lemma 1. *In any equilibrium, both candidates randomize over at least two pure strategies.*

Proof. Suppose that there is an equilibrium in which only one candidate follows a non-degenerated mixed strategy σ_j^* whereas the other candidate chooses a pure strategy e_{-j}^*. Hereafter, denote by S_j^* the support of σ_j^*, α_j^* its minimum element, and β_j^* its maximum element, respectively.

First, consider an equilibrium (σ_i^*, e_c^*). Since σ_i^* is a non-degenerated mixed strategy, $\alpha_i^* < \beta_i^*$. Suppose that $\beta_i^* < e_c^*$. In this case, choosing e_c^* with probability one yields the incumbent a higher expected payoff than following σ_i^*. Suppose that $e_c^* \leq \alpha_i^*$. Then, the incumbent is better off loading probability one on 1 if $e_c^* = 0$ and on e_c^* if $e_c^* > 0$. Suppose that $\alpha_i^* < e_c^* \leq \beta_i^*$. Again, the incumbent can increase her expected payoff by loading probability one on e_c^*.

Next, consider an equilibrium (e_i^*, σ_c^*). This implies that $\alpha_c^* < \beta_c^*$. Suppose that $\beta_c^* < e_i^*$ or $e_i^* < \alpha_c^*$. In either case, the incumbent has an incentive to unilaterally deviate to β_c^*. Suppose that $\alpha_c^* \leq e_i^* < \beta_c^*$. Then, the challenger can increase her expected payoff by expending $e_i^* + 1$ with probability one. Suppose that $\alpha_c^* < e_i^* = \beta_c^*$. Since the incumbent wins the prize for sure, the challenger is better off loading probability one on 0. $\square$

It follows from Nash (1950) that there exists at least one (non-degenerated) mixed-strategy equilibrium in the game. Let $\sigma^* = (\sigma_i^*, \sigma_c^*)$ be a mixed-strategy equilibrium for the game and $u_j(\sigma^*) = u_j(\sigma_j^*, \sigma_{-j}^*) = \sum_{e \in E} \sigma_j^*(e) \cdot u_j(e, \sigma_{-j}^*)$ the corresponding equilibrium payoff of candidate j, where $u_j(e, \sigma_{-j}^*)$ denotes candidate j's expected payoff from expending e given the other candidate's equilibrium mixed strategy σ_{-j}^*. Then, $u_j(\sigma^*) = u_j(e, \sigma_{-j}^*)$ for $e \in S_j^*$ and $u_j(\sigma^*) \geq u_j(e, \sigma_{-j}^*)$ for $e \notin S_j^*$.

Lemma 2. *In any equilibrium,*

(a) $\alpha_c^* = 0$,

(b) $\alpha_i^* = m$,

(c) $\{1, 2, \ldots, m\} \notin S_c^*$,

(d) $u_c(\sigma^*) = 0$.

Proof. (a) Show first that $\alpha_i^* \geq \alpha_c^*$ and then that $\alpha_c^* = 0$. Suppose that $\alpha_i^* < \alpha_c^*$. Since $u_i(\alpha_i^*, \sigma_c^*) = -\alpha_i^* \leq 0$, the incumbent can increase her expected payoff by assigning probability one to l, contradicting $\alpha_i^* < \alpha_c^*$.

Suppose that $\alpha_c^* > 0$. This implies that $\alpha_i^* \geq \alpha_c^* > 0$, and thereby $u_c(\alpha_c^*, \sigma_i^*) = -\alpha_c^* < 0$. The challenger is better off choosing 0 with probability one. A contradiction.

(b) Suppose that $\alpha_i^* \neq m$. If $\alpha_i^* < m$, $u_i(\alpha_i^*, \sigma_c^*) = -\alpha_i^* \leq 0$. The incumbent's mixed strategy that assigns probability one to l strictly dominates σ_i^*. This contradicts $\alpha_i^* \in S_i^*$. If $\alpha_i^* > m$, all $e \in E$ such that $0 < e \leq \alpha_i^*$ are not in S_c^* because the challenger's mixed strategy that assigns probability one to 0 strictly dominates these pure strategies. In this case, the incumbent's expected payoffs from expending α_i^* and $m \notin S_i^*$ are

$$u_i(\alpha_i^*, \sigma_c^*) = r \cdot \sum_{e \leq \alpha_i^*} \sigma_c^*(e) - \alpha_i^* = r \cdot \sigma_c^*(0) - \alpha_i^*,$$

and

$$u_i(m, \sigma_c^*) = r \cdot \sum_{e \leq m} \sigma_c^*(e) - m = r \cdot \sigma_c^*(0) - m,$$

respectively. Since $\alpha_i^* > m$, $u_i(\alpha_i^*, \sigma_c^*) < u_i(m, \sigma_c^*)$, which contradicts $\alpha_i^* \in S_i^*$.

(c) Suppose that there exists $\tilde{e} \in \{1, 2, \ldots, m\}$ such that $\tilde{e} \in S_c^*$. It immediately follows from (b) that $u_c(\tilde{e}, \sigma_i^*) = -\tilde{e}$. Then, the challenger can increase her expected payoff by loading probability one on 0. This contradicts $\tilde{e} \in S_c^*$.

(d) The challenger can assure her a payoff of 0 by expending $0 \in S_c^*$, independent of what the incumbent does. Therefore, $u_c(\sigma^*) = 0$. $\square$

Lemma 3. *In any equilibrium,*

(a) $\beta_i^* = \beta_c^* = l$,

(b) $u_i(\sigma^*) = r - l$.

Proof. (a) First, show that $\beta_i^* = \beta_c^*$. Suppose that $\beta_i^* \neq \beta_c^*$. If $\beta_i^* < \beta_c^*$, then the challenger's expected payoff from expending β_c^* is $u_c(\beta_c^*, \sigma_i^*) = r - \beta_c^* > 0$, which contradicts Lemma 2 (d). If $\beta_i^* > \beta_c^*$, the incumbent's expected payoff from expending β_i^* is $u_i(\beta_i^*, \sigma_c^*) = r - \beta_i^*$. Then, the incumbent's mixed strategy that assigns probability 1 on β_c^* strictly dominates σ_i^* because $u_i(\beta_c^*, \sigma_c^*) = r - \beta_c^* > r - \beta_i^*$. This contradicts $\beta_i^* \in S_i^*$.

Next, show that $\beta_i^* = \beta_c^* = l$. Suppose that $\beta_i^* = \beta_c^* < l$. By Lemma 2 (d), $u_c(\beta_c^*, \sigma_i^*) = 0$. But, the challenger is better off choosing $\beta_c^* + 1 \notin S_c^*$ with probability one because $u_c(\beta_c^* + 1, \sigma_i^*) = r - (\beta_c^* + 1) > 0$. A contradiction to $\beta_c^* \in S_c^*$.

(b) The incumbent can surely receive a payoff of $r - l$ by expending $l \in S_i^*$, independent of what the challenger does. Therefore, $u_i(\sigma^*) = r - l$. □

Lemma 4. *In any equilibrium, $\{m+1, m+2, \ldots, l-1\} \in S_j^*$ for all j.*

Proof. Suppose that there exist $\hat{e} \in \{m+1, m+2, \ldots, l-1\}$ such that $\hat{e} \notin S_j^*$ for some j. For all j, define $e_j^L \equiv \max\{e \in S_j^* | \alpha_j^* \leq e < \hat{e}\}$ and $e_j^H \equiv \min\{e \in S_j^* | \hat{e} < e \leq l\}$.

Case 1: $\hat{e} \in S_i^*$ and $\hat{e} \notin S_c^*$. The incumbent's expected payoffs from expending $\hat{e}$ and e_c^L are

$$u_i(\hat{e}, \sigma_c^*) = r \cdot \sum_{e \leq \hat{e}} \sigma_c^*(e) - \hat{e} = r \cdot \sum_{e \leq e_c^L} \sigma_c^*(e) - \hat{e},$$

and

$$u_i(e_c^L, \sigma_c^*) = r \cdot \sum_{e \leq e_c^L} \sigma_c^*(e) - e_c^L,$$

respectively. Since $\hat{e} > e_c^L$, $u_i(\hat{e}, \sigma_c^*) < u_i(e_c^L, \sigma_c^*)$, which contradicts $\hat{e} \in S_i^*$.

Case 2: $\hat{e} \notin S_i^*$ and $\hat{e} \in S_c^*$. Suppose that $\hat{e} \notin S_i^*$ and $\hat{e} \in S_c^*$. If $e_i^H < e_c^H$, the incumbent's expected payoffs from expending $\hat{e}$ and e_i^H are

$$u_i(\hat{e}, \sigma_c^*) = r \cdot \sum_{e \leq \hat{e}} \sigma_c^*(e) - \hat{e},$$

and

$$u_i(e_i^H, \sigma_c^*) = r \cdot \sum_{e \leq e_i^H} \sigma_c^*(e) - e_i^H = r \cdot \sum_{e \leq \hat{e}} \sigma_c^*(e) - e_i^H,$$

respectively. Since $\hat{e} < e_i^H$, $u_i(\hat{e}, \sigma_c^*) > u_i(e_i^H, \sigma_c^*)$. A contradiction to $e_i^H \in S_i^*$. If $e_i^H \geq e_c^H$, the challenger's expected payoffs from expending $\hat{e}$ and e_c^H are

$$u_c(\hat{e}, \sigma_i^*) = r \cdot \sum_{e < \hat{e}} \sigma_i^*(e) - \hat{e} = r \cdot \sum_{e \leq e_i^L} \sigma_i^*(e) - \hat{e},$$

and

$$u_c(e_c^H, \sigma_i^*) = r \cdot \sum_{e<e_c^H} \sigma_i^*(e) - e_c^H = r \cdot \sum_{e \le e_i^L} \sigma_i^*(e) - e_c^H,$$

respectively. Since $\hat{e} < e_c^H$, $u_c(\hat{e}, \sigma_i^*) > u_c(e_c^H, \sigma_i^*)$, which contradicts $e_c^H \in S_c^*$.

Case 3: $\hat{e} \notin S_j^*$ for all j. Suppose that $\hat{e} \notin S_j^*$ for all j. If $e_i^H < e_c^H$, the incumbent's expected payoffs from expending e_i^H and e_c^L are

$$u_i(e_i^H, \sigma_c^*) = r \cdot \sum_{e \le e_i^H} \sigma_c^*(e) - e_i^H = r \cdot \sum_{e \le e_c^L} \sigma_c^*(e) - e_i^H,$$

and

$$u_i(e_c^L, \sigma_c^*) = r \cdot \sum_{e \le e_c^L} \sigma_c^*(e) - e_c^L,$$

respectively. Since $e_c^L < \hat{e} < e_i^H$, $u_i(e_i^H, \sigma_c^*) < u_i(e_c^L, \sigma_c^*)$. A contradiction to $e_i^H \in S_i^*$. If $e_i^H \ge e_c^H$, the challenger's expected payoffs from expending $e_i^L + 1$ and e_c^H are

$$u_c(e_i^L + 1, \sigma_i^*) = r \cdot \sum_{e<e_i^L+1} \sigma_i^*(e) - (e_i^L + 1) = r \cdot \sum_{e \le e_i^L} \sigma_i^*(e) - (e_i^L + 1),$$

and

$$u_c(e_c^H, \sigma_i^*) = r \cdot \sum_{e<e_c^H} \sigma_i^*(e) - e_c^H = r \cdot \sum_{e \le e_i^L} \sigma_i^*(e) - e_c^H,$$

respectively. Since $e_i^L + 1 \le \hat{e} < e_c^H$, $u_c(e_i^L + 1, \sigma_i^*) > u_c(e_c^H, \sigma_i^*)$. This contradicts $e_c^H \in S_c^*$. □

Lemma 5. *There exists a unique equilibrium in mixed strategies (σ_i^*, σ_c^*) characterized by (1) and (2).*

Proof. It follows from Lemmas 2, 3, and 4 that in any equilibrium, $S_i^* = \{m, m+1, \ldots, l\}$, $S_c^* = \{0\} \cup \{m+1, m+2, \ldots, l\}$, $u_i(\sigma^*) = r - l$, and $u_c(\sigma^*) = 0$. This implies that $u_i(e, \sigma_c^*) = r - l$ for all $e \in S_i^*$ and $u_c(e, \sigma_i^*) = 0$ for all $e \in S_c^*$. To obtain such an equilibrium, σ_c^* must solve the following system of $(l - m + 1)$ linear equations with $(l-m+1)$ unknowns:

$$\begin{cases} r \cdot \sigma_c^*(0) - m & = r - l \\ r \cdot [\sigma_c^*(0) + \sigma_c^*(m+1)] - (m+1) & = r - l \\ r \cdot [\sigma_c^*(0) + \sigma_c^*(m+1) + \sigma_c^*(m+2)] - (m+2) & = r - l \\ \vdots \\ r \cdot [\sigma_c^*(0) + \sigma_c^*(m+1) + \sigma_c^*(m+2) \cdots + \sigma_c^*(l-1)] - (l-1) & = r - l \\ r \cdot [\sigma_c^*(0) + \sigma_c^*(m+1) + \sigma_c^*(m+2) \cdots + \sigma_c^*(l)] - l & = r - l \end{cases}$$

This system can be expressed as follows:

$$\underbrace{\begin{bmatrix} r & 0 & 0 & \dots & 0 & 0 \\ r & r & 0 & \dots & 0 & 0 \\ r & r & r & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ r & r & r & \dots & r & 0 \\ r & r & r & \dots & r & r \end{bmatrix}}_{(l-m+1)\times(l-m+1)} \underbrace{\begin{bmatrix} \sigma_c^*(0) \\ \sigma_c^*(m+1) \\ \sigma_c^*(m+2) \\ \vdots \\ \sigma_c^*(l-1) \\ \sigma_c^*(l) \end{bmatrix}}_{(l-m+1)\times 1} = \underbrace{\begin{bmatrix} r-l+m \\ r-l+m+1 \\ r-l+m+2 \\ \vdots \\ r-1 \\ r \end{bmatrix}}_{(l-m+1)\times 1} \tag{A.1}$$

The number of linear equations is equal to the number of unknowns, and the determinant of the leftmost square matrix of the system (A.1) is nonsingular because $r^{l-m+1} > 0$. Hence, there exists a unique solution of the system. Recursive substitution yields the solution for the system. Since $r > l > m$, it is straightforward to see that $0 < \sigma_c^*(e) < 1$ for all $e \in S_c^*$ and $\sum_{e \in S_c^*} \sigma_c^*(e) = 1$.

Similarly, σ_i^* must solve the following system of $(l-m+1)$ linear equations with $(l-m+1)$ unknowns:

$$\begin{cases} r \cdot \sigma_i^*(m) - (m+1) & = 0 \\ r \cdot [\sigma_i^*(m) + \sigma_i^*(m+1)] - (m+2) & = 0 \\ r \cdot [\sigma_i^*(m) + \sigma_i^*(m+1) + \sigma_i^*(m+2)] - (m+3) & = 0 \\ \vdots \\ r \cdot [\sigma_i^*(m) + \sigma_i^*(m+1) + \sigma_i^*(m+2) \cdots + \sigma_i^*(l-1)] - l & = 0 \\ \sigma_i^*(m) + \sigma_i^*(m+1) + \sigma_i^*(m+2) \cdots + \sigma_i^*(l-1) + \sigma_i^*(l) & = 1 \end{cases}$$

This system can be expressed as follows:

$$\underbrace{\begin{bmatrix} r & 0 & 0 & \dots & 0 & 0 & 0 \\ r & r & 0 & \dots & 0 & 0 & 0 \\ r & r & r & \dots & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ r & r & r & \dots & r & 0 & 0 \\ r & r & r & \dots & r & r & 0 \\ 1 & 1 & 1 & \dots & 1 & 1 & 1 \end{bmatrix}}_{(l-m+1)\times(l-m+1)} \underbrace{\begin{bmatrix} \sigma_i^*(m) \\ \sigma_i^*(m+1) \\ \sigma_i^*(m+2) \\ \vdots \\ \sigma_i^*(l-2) \\ \sigma_i^*(l-1) \\ \sigma_i^*(l) \end{bmatrix}}_{(l-m+1)\times 1} = \underbrace{\begin{bmatrix} m+1 \\ m+2 \\ m+3 \\ \vdots \\ l-1 \\ l \\ 1 \end{bmatrix}}_{(l-m+1)\times 1} \tag{A.2}$$

Again, the number of linear equations is equal to the number of unknowns, and the determinant of the leftmost square matrix of the system (A.2) is nonsingular because $r^{l-m} > 0$. Thus, this system also possesses a unique solution, and applying recursive substitution yields the solution for this system. As before, since $r > l > m$, it is easy to see that $0 < \sigma_i^*(e) < 1$ for all $e \in S_i^*$ and $\sum_{e \in S_i^*} \sigma_i^*(e) = 1$. □

Lemmas 1–5 complete the proof of Proposition 1. □

B Instructions and Control Questions for Treatment *LL* (originally written in German)

INTERACTIVE DECISION MAKING EXPERIMENT
SUBJECT INSTRUCTIONS

Introduction

Welcome to an interactive decision making experiment. During this experiment you will be asked to make a large number of decisions and so will the other participants.

Please read the instructions carefully. Your decisions, as well as the decisions of the other participants, will determine your payoff according to the rules that will be explained shortly. The points you earn in the experiment will be converted to euros and paid to you in cash at the end of the experiment. In addition, you will receive a show-up fee of €2.50 for having shown up on time.

Please note that hereafter any form of communication between the participants is strictly prohibited. If you have any questions, please raise your hand. The experimenter will come to assist you.

Description of the Experiment

This experiment is fully computerized. You will be making your decisions by clicking on appropriate buttons on the screen. All the participants are reading the same instructions and taking part in this experiment for the first time, as you are.

A total of 32 persons are participating in this experiment. At the beginning of the experiment, the computer will randomly form 4 groups of 8 participants. Group composition will remain the same throughout the experiment. In other words, you will never be interacting with participants of the other three groups. Then, for each group the computer will randomly assign four participants to the role of **X** and the other four participants to the role of **Y**. Therefore, there are 4 Xs and 4 Ys in each group. Your role will remain the same throughout the experiment.

At the beginning of each round, you will randomly be paired with another participant in your group who is assigned the opposite role. This means that if you are X (Y), you will randomly be paired with one of the 4 Ys (4 Xs) in your group. You may or may not be paired with the same opponent in a row. However, the identity of your opponent will not be disclosed to you. Similarly, your identity will not be revealed to your opponent.

Description of the Rules

The experiment consists of **60** identical rounds. Your final payoff will be determined by the total points you earn over all of the 60 rounds.

On each round, you and your opponent will have the opportunity to win a prize worth **15 points**. Whether you will win the prize or not depends on

- the number of tokens you buy,
- the number of tokens your opponent buys, and
- which role you are assigned.

At the beginning of each round, each of you will receive an endowment of **14 points** and be asked how many tokens to buy at the rate **1 token = 1 point**. **The maximum number of tokens each of you is allowed to buy is 8 tokens**. Thus, the number of tokens you buy has to be one of the following numbers:

$$\mathbf{0, 1, 2, 3, 4, 5, 6, 7, 8}$$

When you decide how many tokens to buy, you will not be able to observe the number of tokens your opponent buys. Nor will your opponent be able to observe the number of tokens you buy.

The winner of the prize will be determined as follows:

1. Suppose that both X and Y buy 0 token. Then, neither of them will win the prize.
2. Suppose that only X buys more than 0 token. Then, X will win the prize.
3. Suppose that only Y buys more than 0 token. Then, Y will win the prize.
4. Suppose that both X and Y buy more than 0 token. Then,
   (a) if X buys more tokens than Y, X will win the prize.
   (b) if Y buys more tokens than X, Y will win the prize.
   (c) if both X and Y buy the same number of tokens, X will win the prize.

Summary: Only those who buy more than 0 token will be considered for the prize. If you buy more than 0 token but your opponent buys no token, you will win the prize. If both you and your opponent buy more than 0 tokens, whoever buys more tokens will win the prize. If both you and your opponent buy the same number of tokens, whoever in the role of X will win the prize.

Please remember that your tokens will not be refunded, irrespective of whether you win the prize or not. You will keep the points you do not spend.

Computation of the Payoff

Your payoff will be computed exactly the same way across the two roles.

1. Suppose that you buy 0 token. Then, you do not need to pay anything, nor do you win the prize. Therefore,

$$\boxed{\begin{aligned}\text{your payoff} &= \text{endowment}\\ &= 14\end{aligned}}$$

2. Suppose that you buy more than 0 token. Since 1 token = 1 point, you need to pay the same number of points as the number of tokens you buy. Then, your payoff is computed as follows:

   (a) If you win the prize,

$$\boxed{\begin{aligned}\text{your payoff} &= \text{endowment} - \text{number of tokens} + \text{prize}\\ &= 14 - \text{number of tokens} + 15\end{aligned}}$$

   (b) If you do not win the prize,

$$\boxed{\begin{aligned}\text{your payoff} &= \text{endowment} - \text{number of tokens}\\ &= 14 - \text{number of tokens}\end{aligned}}$$

To assist you in calculating payoffs, Table 1 (on a separate sheet of paper) shows payoffs for all possible combinations of the decisions of X and Y. Each row represents the number of tokens bought by X whereas each column represents the number of tokens bought by Y. In each cell, the first number is the payoff to X and the second number is the payoff to Y. Below are examples that illustrate how to read Table 1.

Example 1: Suppose that X buys 5 tokens and Y buys 0 token. X wins the prize. The cell that depicts their payoffs is located at the intersection of the row labeled "**5**" and the column labeled "**0**". X's payoff is 24 ($= 14 - 5 + 15$) points whereas Y's payoff is 14 points.

Example 2: Suppose that X buys 2 tokens and Y buys 7 tokens. Y wins the prize. The cell that depicts their payoffs is located at the intersection of the row labeled "**2**" and the column labeled "**7**". X's payoff is 12 ($= 14 - 2$) points whereas Y's payoff is 22 ($= 14 - 7 + 15$) points.

Example 3: Suppose that both X and Y buy 3 tokens. X wins the prize. The cell that depicts their payoffs is located at the intersection of the row labeled "**3**" and the column labeled "**3**". X's payoff is 26 ($= 14 - 3 + 15$) points whereas Y's payoff is 11 ($= 14 - 3$) points.

Procedure

After all participants indicate their readiness for the experiment, the experimenter will read the instructions aloud. Then, the computer will give you a series of nine questions designed to check your understanding of the instructions. These questions will appear on the screen one by one. **The computer will not allow you to move onto the next question until you correctly answer the one on the screen**. Please remember that you can consult the instructions anytime you like.

After all participants answer the nine questions correctly, the experiment will begin. Before playing the first round, the computer will inform you of

- your role in this experiment, and
- your conversion rate (i.e., the rate at which the total points you earn in this experiment will be converted to your earnings in euros at the end of the experiment).

Also, the experimenter will privately give you a small piece of paper on which your role and conversion rate are printed. The roles and conversion rates of the other participants will not be disclosed to you. Nor will your role and conversion rate be revealed to the other participants.

After the experimenter makes sure that each participant receives the paper on which his/her role and conversion rate are printed, the first round will begin. Each round will identically be structured as follows. You will randomly be paired with another participant in your group who is assigned to the opposite role. Then, the computer will exhibit a decision screen that displays nine different numbers of tokens, namely, $0, 1, 2, \ldots, 7, 8$, and you will be asked to choose the number of tokens you want to purchase. When you are ready to submit your decision, please click on the Submit button on the screen. You will be forwarded to a confirmation screen in which you will be asked to confirm your decision. When you confirm your decision, please click on the Confirm button on the screen.

After all participants confirm their decisions, a results screen will inform you of

- the number of tokens bought by you,
- the number of tokens bought by your opponent,
- outcome and payoff for the current round, and
- current balance (i.e., total points you have accumulated so far).

When you are ready for the next round, please click on the Continue button on the screen.

End of the Experiment

After completing the experiment, a summary screen will display

- the total points you have accumulated, and
- the corresponding earnings in euros.

Please remain at your cubicle until asked to come forward and receive payment for the experiment.

When you are ready for the experiment, please click on the I'm ready button on the screen.

Please remember that no communication is allowed during the experiment. If you encounter any difficulties, please raise your hand. The experimenter will come to assist you.

		Number of Tokens Bought by Y								
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Number of Tokens Bought by X	**0**	14, 14	14, 28	14, 27	14, 26	14, 25	14, 24	14, 23	14, 22	14, 21
	1	28, 14	28, 13	13, 27	13, 26	13, 25	13, 24	13, 23	13, 22	13, 21
	2	27, 14	27, 13	27, 12	12, 26	12, 25	12, 24	12, 23	12, 22	12, 21
	3	26, 14	26, 13	26, 12	26, 11	11, 25	11, 24	11, 23	11, 22	11, 21
	4	25, 14	25, 13	25, 12	25, 11	25, 10	10, 24	10, 23	10, 22	10, 21
	5	24, 14	24, 13	24, 12	24, 11	24, 10	24, 9	9, 23	9, 22	9, 21
	6	23, 14	23, 13	23, 12	23, 11	23, 10	23, 9	23, 8	8, 22	8, 21
	7	22, 14	22, 13	22, 12	22, 11	22, 10	22, 9	22, 8	22, 7	7, 21
	8	21, 14	21, 13	21, 12	21, 11	21, 10	21, 9	21, 8	21, 7	21, 6

Table 1: Payoff table (in points)

Control Questions

Q.1 (True/False Question) Your role will change every round.

True / False

Answer: False. Your role will stay the same throughout the experiment.

Q.2 (True/False Question) You will never be paired with the same opponent in a row.

True / False

Answer: False. You may or may not be paired with the same opponent in a row. However, the identity of your opponent will not be disclosed to you. Similarly, your identity will not be revealed to your opponent.

Q.3 (True/False Question) If you do not win the prize, your tokens will be refunded.

True / False

Answer: False. Tokens are non-refundable. Thus, your tokens will not refunded, irrespective of whether you win the prize or not.

Q.4 (Multiple Choice Question) In a round, both X and Y buy 0 tokens. Who will win the prize?

A. X will win the prize.

B. Y will win the prize.

C. Neither X nor Y will win the prize.

Answer: C. Only those who buy more than 0 token will be considered for the prize. Since both X and Y buy 0 token, there will be no winner.

Q.5 (Multiple Choice Question) In a round, X buys 0 token whereas Y buys 7 tokens. Who will win the prize?

A. X will win the prize.

B. Y will win the prize.

C. Neither X nor Y will win the prize.

Answer: B. Y will win the prize because only Y buys more than 0 token.

Q.6 (Multiple Choice Question) In a round, X buys 6 tokens whereas Y buys 2 tokens. Who will win the prize?

A. X will win the prize.

B. Y will win the prize.

C. Neither X nor Y will win the prize.

Answer: A. X will win the prize because X buys more tokens than Y.

Q.7 (Multiple Choice Question) In a round, both X and Y buy 6 tokens. Who will win the prize?

A. X will win the prize.

B. Y will win the prize.

C. Neither X nor Y will win the prize.

Answer: A. Since both X and Y buy the same number of tokens, X will win the prize.

Q.8 (Multiple Choice Question) In a round, X earned 24 points and Y earned 9 points. How many tokens did they buy for this round? Who won the prize? [Hint: See Table 1 in the instructions.]

A. X bought 5 tokens and Y bought 8 tokens. X won the prize.

B. X bought 8 tokens and Y bought 5 tokens. Y won the prize.

C. Both X and Y bought 5 tokens. X won the prize.

D. Both X and Y bought 5 tokens. Y won the prize.

Answer: C. Find the cell in Table 1 in which the first number is 24 and the second number is 9. The cell is located at the intersection of the row labeled "**5**" and the column labeled "**5**". In this case, X won the prize.

Q.9 (Multiple Choice Question) In a round, X earned 13 points and Y earned 23 points. How many tokens did they buy for this round? Who won the prize? [Hint: See Table 1 in the instructions.]

A. X bought 6 tokens and Y bought 1 token. X won the prize.

B. X bought 2 tokens and Y bought 4 tokens. Y won the prize.

C. X bought 4 tokens and Y bought 2 tokens. X won the prize.

D. X bought 1 token and Y bought 6 tokens. Y won the prize.

Answer: D. Find the cell in Table 1 in which the first number is 13 and the second number is 23. The cell is located at the intersection of the row labeled "**1**" and the column labeled "**6**". In this case, Y won the prize.

Figures

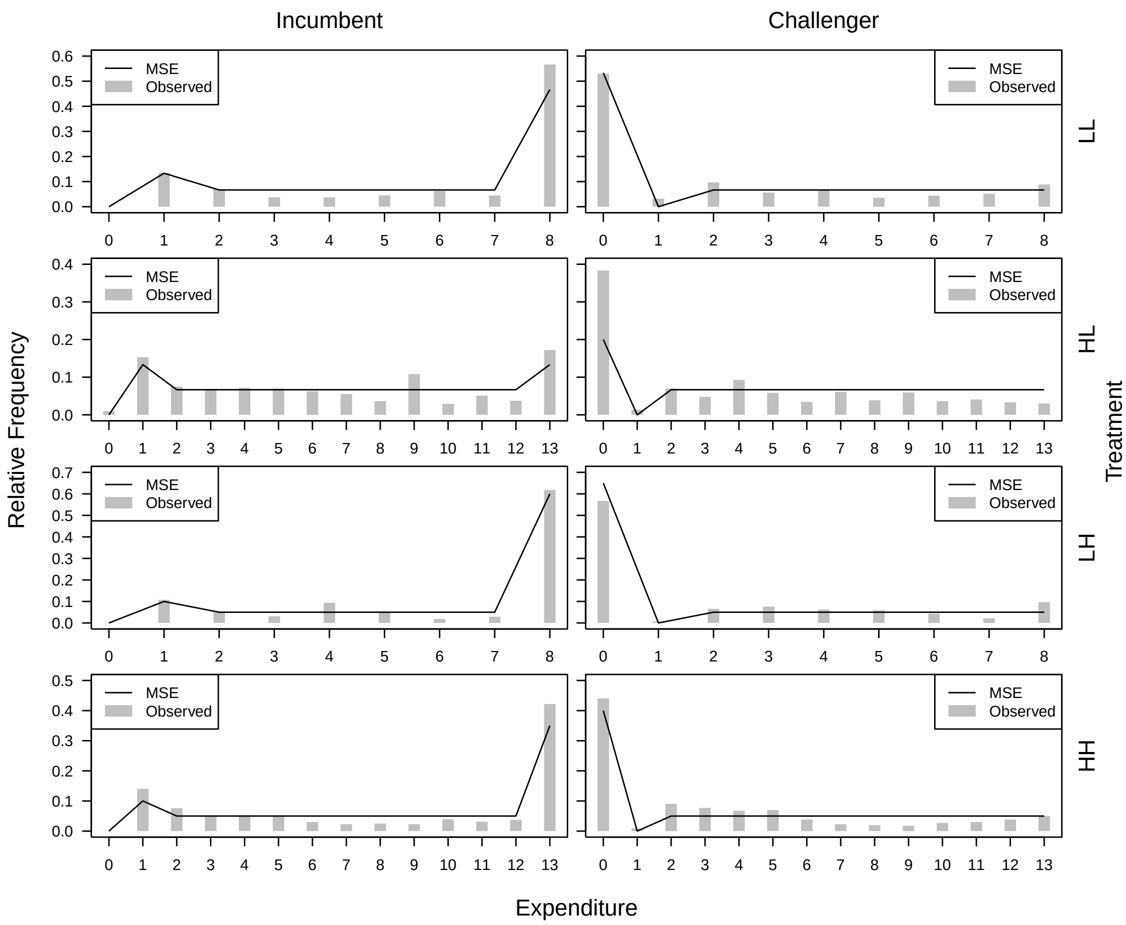

Figure 1: Mixed-strategy equilibrium and the observed relative frequency of expenditures by treatment and role.

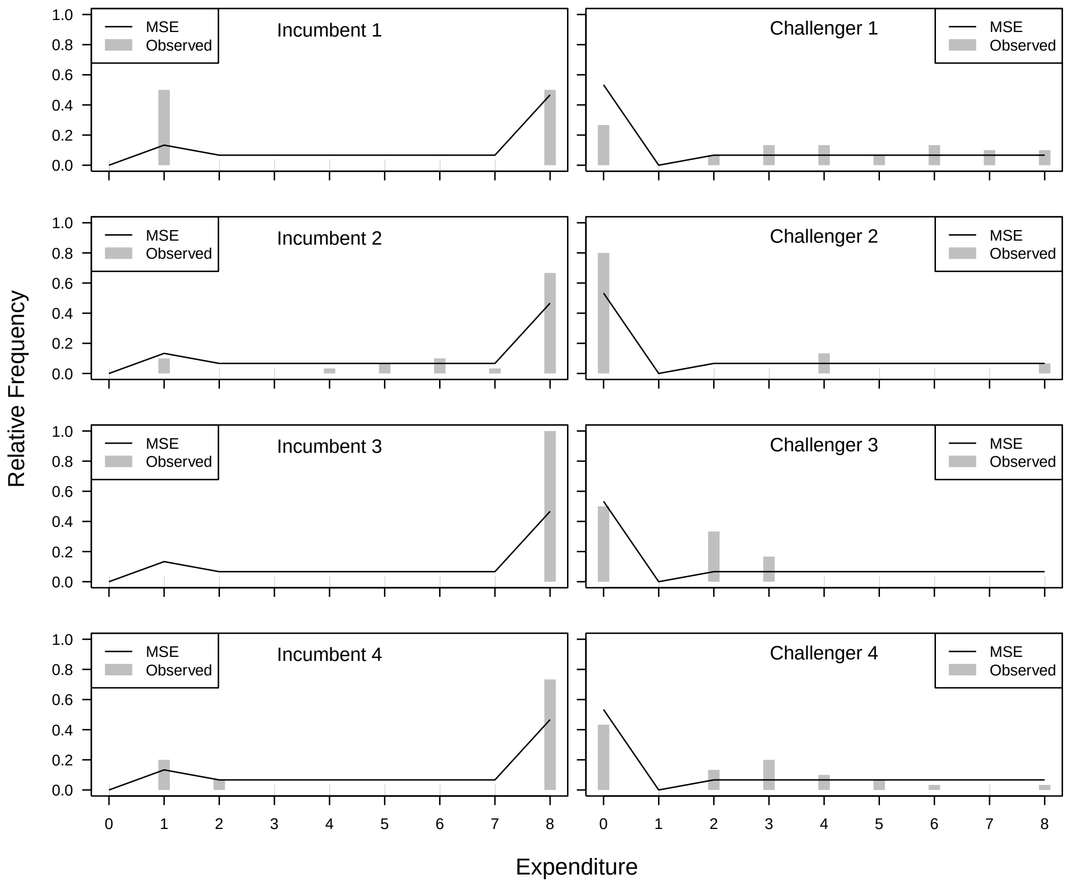

Figure 2: Mixed-strategy equilibrium and the relative frequency distribution of expenditures by subject in group 1, treatment *LL*.

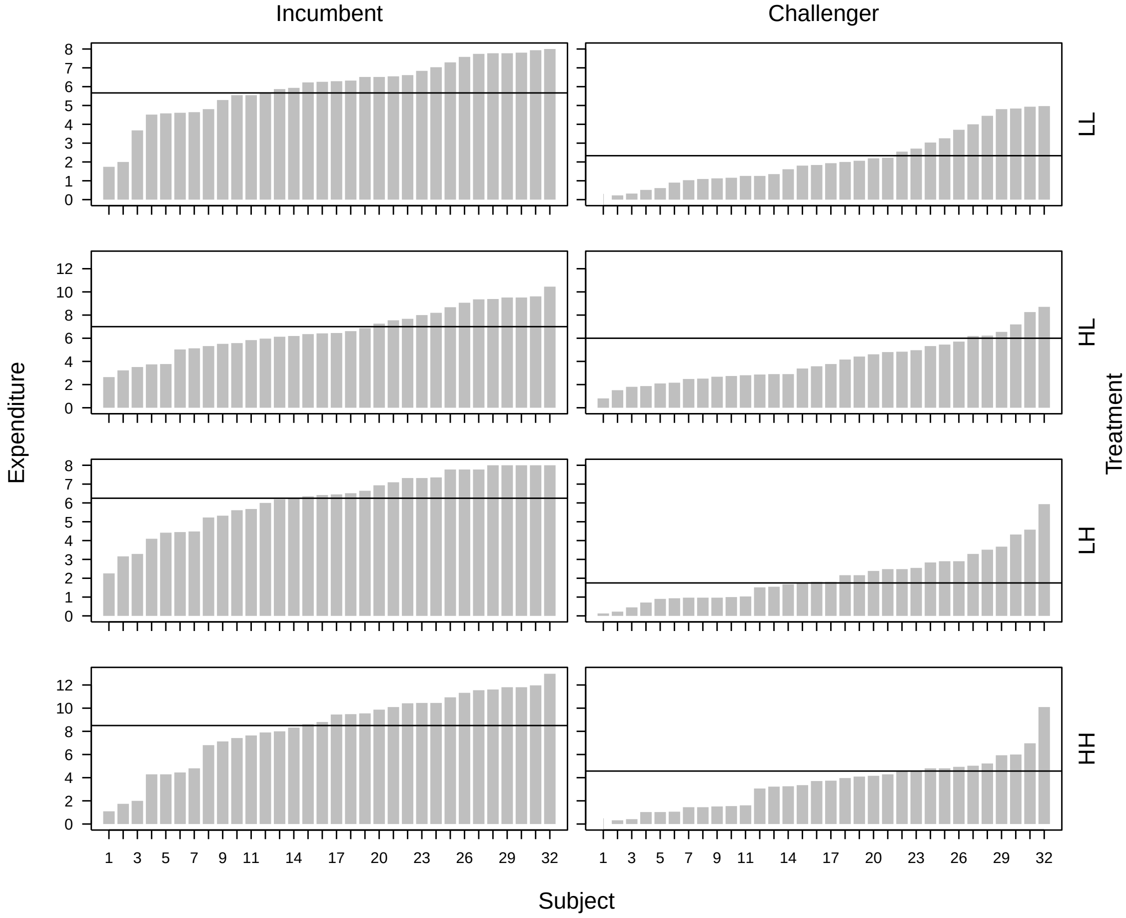

Figure 3: Distribution of individual mean expenditures.

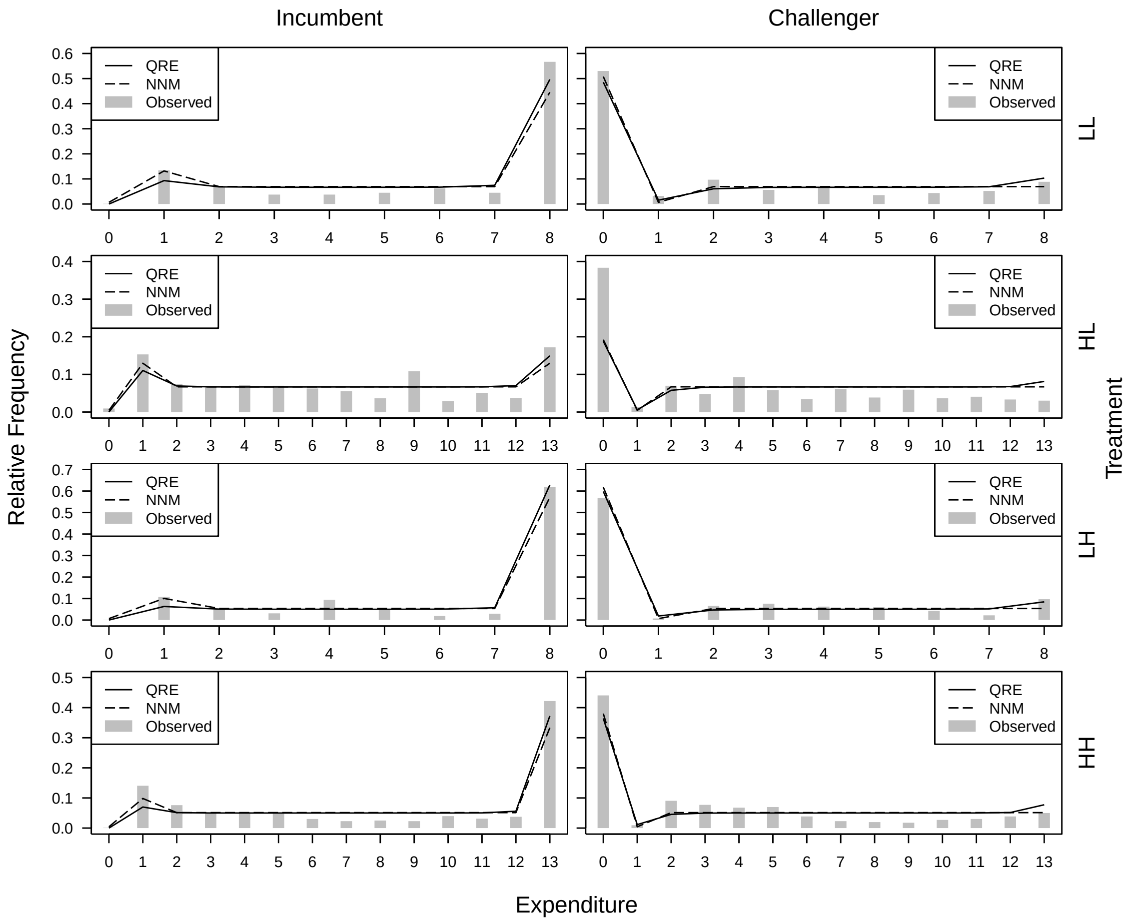

Figure 4: Quantal response equilibrium, noisy Nash model, and the observed relative frequency distribution of expenditures by treatment and role.

Tables

	Treatment (t)			
	LL	HL	LH	HH
Spending limit (l)	8	13	8	13
Prize (r)	15	15	20	20
$\mu^*_{i,t}$	5.667	7	6.25	8.5
$\mu^*_{c,t}$	2.333	6	1.75	4.5
$\theta^*_{i,t}$	0.844	0.6	0.913	0.775
$\theta^*_{c,t}$	0.156	0.4	0.087	0.225

Table 1: Values of the parameters for the experiment and the theoretical predictions.

Treatment	Incumbent				Challenger			
	Expenditure		Winning Rate		Expenditure		Winning Rate	
	Observed	MSE	Observed	MSE	Observed	MSE	Observed	MSE
LL	5.984	5.667	0.868	0.844	2.166	2.333	0.132	0.156
HL	6.711	7	0.712	0.6	4.043	6	0.286	0.4
LH	6.196	6.25	0.891	0.913	2.098	1.75	0.109	0.087
HH	8.316	8.5	0.812	0.775	3.467	4.5	0.188	0.225

Table 2: Observed and predicted mean expenditures and winning rates by treatment and role.

Role	*LL* vs. *HL*	*LH* vs. *HH*
Incumbent	Reject ($p = 0.0474$)	Reject ($p = 0.0000$)
Challenger	Reject ($p < 0.0001$)	Reject ($p = 0.0012$)

Table 3: Pairwise comparisons of mean expenditures between two treatments with the one-sided permutation test at the 5% significance level.

Treatment	Incumbent	Challenger
LL	20 (62.5%)	25 (78.1%)
HL	28 (87.5%)	24 (75%)
LH	20 (62.5%)	15 (46.9%)
HH	21 (65.6%)	25 (78.1%)

Table 4: Number and proportion of subjects for whom the Kolmogorov-Smirnov test rejected the null hypothesis of equilibrium play at the 5% significance level.

Treatment	Incumbent				Challenger			
	Observed	MSE	QRE	NNM	Observed	MSE	QRE	NNM
LL	5.984	5.667	5.927	5.567	2.166	2.333	2.642	2.433
HL	6.711	7	7.239	6.970	4.043	6	6.187	6.030
LH	6.196	6.25	6.494	6.115	2.098	1.75	2.052	1.885
HH	8.316	8.5	8.839	8.380	3.467	4.5	4.877	4.620

Table 5: Observed and predicted mean expenditures by treatment and role.