Appalachian State University

Department of Economics Working Paper

Number 18-16| December 2018

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Francesco Fallucchi
LISER

Abhijit Ramalingam
Appalachian State University

Department of Economics
Appalachian State University
Boone, NC 28608
Phone: (828) 262-2148
Fax: (828) 262-6105
www.business.appstate.edu/economics

Inequality and Competitive Effort: The Roles of Asymmetric Resources, Opportunity and Outcomes

Francesco Fallucchi [a*], Abhijit Ramalingam [b]

[a] LISER - Luxembourg

[b] Department of Economics, Walker College of Business, Appalachian State University, Boone, NC 28608, USA

October 1, 2018

Abstract

We investigate how individuals react to different types of asymmetries in experimental two-player Tullock contests where contestants expend resources to win a prize. We compare the effects of three different sources of asymmetry: resources, abilities and possible outcomes. We find that overall competitive effort is greater in the presence of asymmetric abilities than other inequalities. Unlike other forms, asymmetry in abilities elicits a very aggressive reaction from disadvantaged players relative to their advantaged opponents. Moreover, despite similar average efforts, contestants with an advantage in ability mostly play a 'safe' strategy that secures a higher likelihood of winning the contest, while other advantaged players strategically adapt their efforts to those of their opponents. The Quantal Response Equilibrium (QRE) suggests that financial incentives are less salient in the presence of a biased contest procedure.

JEL Codes: C91, C92, D31, D72

Keywords: rent seeking, contest, experiment, asymmetry, heuristics, QRE

[*]Corresponding author: francesco.fallucchi@liser.lu. 11 Porte des Sciences, 4366 Esch-sur-Arzette - Luxembourg.

1. Introduction

We study the effects of asymmetry on behaviour in a very commonly observed interaction between economic agents: competition. Many forms of competition can be modelled as rent seeking contests à la Tullock (1980), where contestants expend resources to increase their chances of winning a prize. Such contests are common practice in the labour market, for example, job seeking and promotions in the workplace. Other examples include wars, litigation, and sports and electoral contests. In each of these contests, heterogeneity of participants is the norm rather than the exception. Moreover, contestants may differ from one another in various aspects. They may differ in abilities (e.g. different skill levels), resources (e.g. have better funding), or may evaluate the rewards differently (e.g. winning a murder trial is more valuable to the defendant than to the plaintiff). Given the ubiquity of competition, it is important to understand how different asymmetries affects behaviour in this setting.

How do agents respond in competitive environments when facing asymmetries? Empirical evidence provides contrasting answers. On the one hand, they may be discouraged and choose to decrease effort. Brown (2011) finds that professional golfers lower their effort when competing against a 'superstar' golfer, Tiger Woods. Thus, a 'discouragement effect' could lead to lower effort to try and win a contest where the outcome is often seen as a foregone conclusion. On the other hand, agents may increase effort in response. For instance, Heite and Hoisl (2018) find that, in repeated crowdsourcing contests, contestants who compete against higher skilled competitors put in more effort to try and solve harder problems than equally skilled peers that compete against equally or less skilled competitors. The question therefore may be extended to 'which' asymmetry induces more/less effort.

We examine the effects of the above three sources of asymmetries on individuals' rent-seeking effort levels by means of experiments. The laboratory, by enabling control over the type of asymmetry present in the setting, allows us to isolate the causal effects of each. Our subjects repeatedly play a lottery contest in fixed pairs. The baseline treatment reflects a fair contest where contestants are symmetric in all aspects, although the winner-take-all nature of the contest may lead to an ex-post unequal distribution of wealth. We label asymmetries according to the variable of interest that is affected: (i) *asymmetric resources*, when contestants have different initial resource endowments, (ii) *asymmetric opportunities*, where contestants have different abilities to affect the outcome (or cost of effort), and (iii) *asymmetric outcomes*, when the asymmetry is in contestants' prize valuations.

Do different sources of asymmetries have different effects on competitive behaviour? The question relates to a broader debate on 'which inequality' to tackle. The literature proposes different taxonomies of asymmetries based on different criteria adopted, succinctly summarised by Hopkins and Kornienko (2010). Interestingly, the authors in their analysis of asymmetries in tournament settings, do not make a distinction between ability and endowment. In our analysis of the Tullock contest, we keep this distinction. All three types of asymmetry lead to unequal earnings in expected terms. However, different abilities do so by driving a wedge between individuals' *opportunities* to influence the outcome, given *the same level of effort*. The other two types of asymmetry, on the other hand, are a result of factors that are, to a certain extent, exogenous to the contest *mechanism*. To the best of our knowledge, our paper presents a novel investigation of this issue, as previous work in this setting has not *compared* different sources of asymmetry.

Similar to previous experimental findings (see Dechenaux et al., 2015), over-dissipation relative to the equilibrium predictions is persistent in all our treatments. However, and more importantly, our results offer new evidence that the *source* of asymmetry may be a crucial determinant of competitive effort in lottery contests. Contrary to standard predictions, we observe the highest level of expenditure in contests with *asymmetric abilities*, followed by the *symmetric* contest and the contests with *asymmetric resources* and *outcomes*. These aggregate treatment differences are driven *solely* by the behaviour of disadvantaged players; with asymmetric abilities, disadvantaged players put in more effort than do their advantaged counterparts, and far more than do disadvantaged players in other treatments. An analysis of the distribution of expenditures suggests that the Quantal Response Equilibrium (McKelvey and Palfrey, 1995) captures the noise in efforts equally well in symmetric treatment and the treatments with asymmetries in *resources* and *outcomes*, but less well in the presence of asymmetric *abilities*.

We further show, through heatmaps, how subjects' behaviour is linked to opponents' behaviourin each treatment. In the symmetric treatment, it is clear that subjects hold myopic beliefs about their opponents. This is also true for the treatments with asymmetric endowments and prize valuations, suggesting this as the mechanism behind a marked reduction in efforts over time. Advantaged players in the asymmetric ability treatment, however, tend to adopt a clear strategy: their efforts are concentrated around the minimum level that would secure them a greater than 50% chance of winning the prize, regardless of the efforts of their disadvantaged counterparts. In contrast, efforts of their disadvantaged counterparts are spread across the strategy space. Even in later stages of the experiment, subjects with a disadvantage in ability display more volatile behaviour than their advantaged opponents, or any other type of player in the other treatments. The strategy of the advantaged players in this treatment thus appears to be a best response to this volatility.

We find that asymmetries in abilities may be more detrimental to contestants' earnings than the other two sources of asymmetry. This is particularly so for the disadvantaged players – they would have been better off by not exerting any effort, i.e., by not competing *at all*. Our results suggest that, from the point of view of gains in efficiency, targeting reductions in asymmetries in opportunities might be the most fruitful.

The remainder of the paper is organized as follows. In Section 2 we introduce the model, describe the different types of asymmetry that we implement and review the related literature. In Section 3, we describe the design of our experiment. We present and discuss our results in Section 4, and conclude in Section 5.

2. A model of asymmetric competition

We consider a rent-seeking lottery contest between two risk-neutral individuals for a monetary prize. Player i (i = 1, 2) decides her level of rent-seeking effort, $e_i \in [0, E_i]$, to invest in a contest for a prize of value V_i, where E_i is her initial endowment of resources. The probability that player i receives the prize, $p_i(e_i, e_j)$, is given by the lottery contest success function (Tullock, 1980) as follows:

$$p_i(e_i, e_j) = \begin{cases} a_i\, e_i / \left(a_i\, e_i + a_j\, e_j\right) & \text{if } (e_i + e_j) \neq 0 \\ 1/2 & \text{otherwise} \end{cases}, \quad i, j = 1, 2; i \neq j, \qquad (1)$$

where a_i and a_j are player's ability/productivity parameters. For simplicity, we set a_j = 1 and a_i = a. Thus $a \geq 1$ captures players' *relative* abilities/productivities. Player i's expected payoff is given by

$$\pi_i = p_i V_i + (E_i - e_i), \; i = 1, 2. \qquad (2)$$

Assuming that the endowment is not binding, equilibrium efforts are given by

$$e_i^* = \frac{aV_i^2 V_j}{(aV_i + V_j)^2} \text{ and } e_j^* = \frac{aV_i V_j^2}{(aV_i + V_j)^2} \qquad (3)$$

and equilibrium expected payoffs by

$$\pi_i^* = E_i + \frac{a^2 V_i^3}{(aV_i + V_j)^2} \text{ and } \pi_j^* = E_j + \frac{V_j^3}{(aV_i + V_j)^2}. \quad (4)$$

When players are symmetric in all respects we get the standard equilibrium individual (group) effort equal to $V/4$ ($V/2$). In the symmetric case, in equilibrium (or for the same effort), both players have equal influence over the contest outcome, and can expect to earn equal payoffs.

2.1 Implementing asymmetries

In the presence of asymmetries between players, we assume, without loss of generality, that it is always player *i* who is the 'advantaged' player and player *j* the 'disadvantaged' player. We only consider one source of asymmetry at a time – in all cases, except for the variable of interest, contestants are symmetric (equal) in all other respects. We consider the following three sources of asymmetry:

(i) Resource endowments ($E_i > E_j$): Assuming that endowments are large enough, equilibrium efforts are not affected by the asymmetry: $e_i^* = e_j^*$, and equal to those when players are symmetric. However, in equilibrium, $\pi_i^* > \pi_j^*$. Here, the contest is fair as for equal effort, both players have equal influence over the contest outcome.

(ii) Abilities ($a > 1$): In equilibrium, $e_i^* = e_j^* \; \forall \, a$, but lower than when both players have equal influence over the outcome. Predicted individual (group) effort is equal to $e_k^* = \frac{aV}{(a+1)^2} \left(\sum e_k^* = \frac{2aV}{(a+1)^2}\right)$ which is lower than in the symmetric case. However, in equilibrium, $\pi_i^* > \pi_j^*$. In this scenario, inequality in final payoffs is a result of the inequality in players' abilities to influence the outcome of the contest, *even with the same level of effort*.

(iii) Prize valuations ($V_i > V_j$): In equilibrium, $e_i^* > e_j^*$ and $\pi_i^* > \pi_j^*$. Further, the advantaged (disadvantaged) player's equilibrium effort is equal to $e_i^* = \frac{V_i^2 V_j}{(V_i + V_j)^2} \left(e_j^* = \frac{V_i V_j^2}{(V_i + V_j)^2}\right)$, which is higher (lower) than in the symmetric case.[1] Once again, for equal effort, both players have equal influence over the contest outcome, i.e., the contest is fair. Inequality in final payoff is a result of differences in *valuations* of the prize.

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[1] Note that, a redistribution of the prize valuation between the two players leads to a similar decrease in total effort as an asymmetry in abilities. Let $\theta = V_i / V_j$ and $V_i + V_j = 2V$, the condition $\theta = a$ guarantees that group effort is the same under the two types of asymmetry.

2.2 Related literature

A large body of theoretical work studies departures from the standard assumption of symmetry between contestants in the Tullock (1980) model of rent seeking. Allard (1988) first analysed the existence of equilibrium and the extent to which rents are dissipated when contestants face unequal costs of effort. The theoretical literature has since considered other sources of asymmetry – such as prize valuation and ability – either individually (e.g. Hillman and Riley, 1989, Nti, 1998) or jointly (e.g. Baik, 1994). These works generally show that inequalities reduce rent seeking, and explore alternative mechanisms for contest organizers to induce greater effort.[2]

Experimental investigations in contests, on the other hand, predominantly study subjects that are equal in all respects. We are aware of only three experiments that study *individual* behaviour in repeated contests where subjects are not symmetric, all of which consider differences in costs of effort (ability). From previous results, we infer that over-dissipation is persistent in all treatments, irrespective of the level of asymmetry. However, we also note that there is mixed evidence on the effects of asymmetry on contest effort exerted by advantaged and disadvantaged players. Fonseca (2009) finds lower expenditures by disadvantaged players with respect to their advantaged opponents, although the difference in efforts between player types is not significant in the second half of the experiment. Kimbrough et al. (2014) find different results. In their experiment, in the presence of high inequality between players, disadvantaged players expend more resources, while the opposite is true for low inequality. However, in both cases the differences between contestants' efforts are negligible. Finally, Rockenbach and Waligora (2016) find that subjects tend to match previous opponents' expenditures. Therefore, efforts of disadvantaged players are not very different from those of advantaged players in two of the three treatments. Similar results emerge in contests between groups.[3]

[2] See Dari-Mattiacci et al. (2015) for a review of the literature. Asymmetries have also been studied in the related model of rank-order tournaments (Lazear and Rosen, 1981). Among them, Gill and Stone (2010) implement desert concerns theoretically and show that this may have important implications on the level of competition when competing agents have asymmetric abilities.

[3] There are experimental studies of the effects of asymmetries on aspects of rent seeking other than individual effort. Anderson and Stafford (2003) and Anderson and Freeborn (2010) vary the intensity of competitions through cost and entry fees in one-shot contests. Although their findings are relevant to the topic, as an increase in heterogeneity decreases subjects' participation, the authors do not provide information on expenditures by different types. In contests between groups, Bhattacharya (2016) finds that the probabilities of winning a *group* contest are consistent with the theoretical predictions when groups are unequal in either ability or cost, thus establishing the behavioural equivalence between the two ways of framing this type of asymmetries. There is also

Among other inequalities, we are aware of one study by Cohen and Shavit (2012), where subjects played a series of one-shot contests with different asymmetries in prize valuation. While they employ a within-subjects one-shot experiment, and therefore not comparable with the repeated between-subjects experiments discussed above, they find that over dissipation relative to equilibrium is higher in contests with asymmetric prize valuations than in symmetric contests. Moreover, when the total prize valuation is comparable, rent-seeking expenditures are at least as high in the asymmetric case than in the symmetric one, contradicting the standard theoretical predictions.

Finally, although the endowmentdoes not affect the risk-neutral equilibrium predictions, we know from Sheremeta (2011) the endowment does impact choices. However, the asymmetry in endowment within competing agents has not been tested before. To our knowledge, there are no experiments that compare the different asymmetries in lottery contests.[4] Whether individual behaviour in contests is affected by sources of asymmetry other than ability thus remains an open question. Moreover, is behaviour affected to the same degree – both in direction, and in magnitude – by the different sources of asymmetry? Finally, do the different sources of asymmetry have different implications for earnings?

3. Experimental design and predictions

3.1 Design and procedures

The experiment was conducted at the University of East Anglia using student subjects. At the beginning of each session, subjects were randomly assigned to pairs that remained fixed throughout the session (partner matching). The instructions (available in Appendix A) were read aloud by an experimenter, and subjects also had a hard copy that they could refer to at any

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work exploring the effects of heterogeneous abilities/cost in contest between groups (e.g. Brookins et al. 2015). All in all, these works do not compare different sources of inequalities.

[4] The effects of different types of asymmetry have been explored in other settings. In the first price all-pay auction, we are aware of only one attempt to compare combined inequalities in endowment and prize valuations by Hart et al. (2015). The authors find a discouragement of the weak players when the asymmetry is in initial wealth but not when contestants have unequal prize valuations. There have been a few attempts to study the behaviour of subjects with asymmetric power in colonel Blotto games and war of attrition (see Dechenaux et al. (2015) for an updated review). Hargreaves Heap et al. (2015) study asymmetry in endowments between groups that play independent public goods games that are then embedded in a group Tullock contest for an additional prize. However, the underlying public goods game in their study eliminates the overbidding problem as efficiency requires 100% effort. Thus, while their study does include (group) contests, their setting is very different. Moreover, their focus is on cooperation and not on competition.

time. After all questions were answered in private, subjects had to correctly answer a set of control questions that tested their understanding of the game before the experiment could begin.

Subjects played the contest game described above repeatedly for 30 rounds in fixed pairs. In each round, subjects received an endowment of tokens, which they could use to buy virtual lottery tickets. Subjects simultaneously decided their rent seeking efforts, i.e., number of tokens to use to buy tickets. Any tokens not used to buy lottery tickets were kept in a private account and earned a return of 1. The number of lottery tickets bought determined subjects' probabilities of winning the prize according to (1). Once all subjects had made their decisions in a round, they were shown the number of tickets purchased by their competitor, the winning probabilities for each player, the winner in the round, and their earnings (in tokens) from the round. In addition, they were also shown this information for all previous rounds.

The baseline treatment (SYM) was a symmetric contest where subjects were identical in all respects. In particular, one token bought one lottery ticket for both subjects in a pair (a = 1), the prize was worth 80 tokens for both players ($V_i = V_j = 80$), and each subject received a per-round endowment of 95 tokens ($E_i = E_j = 95$).

Our other treatments introduced one source of asymmetry each. The first (ASYM-E) retains all the design features of the baseline treatment with the exception that contestants now receive different endowments at the beginning of each round, i.e. one subject received an endowment (E_i) of 120 tokens while the other received an endowment (E_j) of 80 tokens. The two other treatments implemented asymmetry using a ratio of 3 to 1 in either subjects' abilities (cost of effort) or prize valuations. In ASYM-A, one token bought one lottery ticket for one subject in a pair while one token bought 3 tickets for the other, i.e., $a = 3$. In ASYM-V, the prize was worth 120 tokens to one subject and 40 tokens to the other, i.e., $V_i = 120$ and $V_j = 40$ (or $\theta = 3 = a$). In all asymmetric treatments, apart from the asymmetry parameters, all parameters were the same as in SYM.[5]

In all cases, the instructions made the source of asymmetry clear. Subjects were also reminded of the asymmetry on their decision screens at the beginning of each round. Table 1 summarizes our treatments and lists the number of observations in each.

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[5] The choice of such asymmetric endowments has been dictated by the goal of creating a benchmark treatment between ASYM-E and ASYM-A in terms of expected earnings. In our case, the total endowment of the two players is higher than in other treatments by 10 points. Given previous evidence we should expect, if anything, a higher level of efforts by pairs compared to other treatments, assuming that the asymmetry between contestants would not induce any compensating effect.

Table 1. Summary of treatments (inequalities are underlined)

		Cost	Valuations		Endowments			
Treatment	***Asymmetry?***	***a***	V_i	V_j	E_i	E_j	**# pairs**	**# subjects**
SYM	No	1	80	80	95	95	20	40
ASYM-E	Yes	1	80	80	<u>120</u>	<u>80</u>	20	40
ASYM-A	Yes	<u>3</u>	80	80	95	95	19	38
ASYM-V	Yes	1	<u>120</u>	<u>40</u>	95	95	20	40
					TOTAL		**79**	**158**

The experiment was programmed in z-Tree (Fischbacher, 2007). A total of 158 subjects were recruited from the University subject pool through the software Hroot (Bock et al., 2014). No subject participated in more than one session (between-subject design). A session lasted approximately 45 minutes. Token earnings from all rounds were converted to Pounds at the rate of 35 tokens to £0.10. Prior to being paid, subjects answered a short demographic questionnaire. Average earnings were £11.12, including a £2 (£3) participation fee for advantaged (disadvantaged) subjects.[6]

3.2 Predictions

While inequality in endowment is not expected to affect the symmetric Nash equilibrium prediction, inequalities in either ability or prize valuation reduce total effort in equilibrium. Table 2 presents, for all our treatments, the per-round Nash equilibrium efforts and earnings implied by our experimental parameters for both types of subjects, and for competing pairs as a whole.[7] Finite repetitions do not change the equilibrium predictions. For purposes of exposition, we treat subjects in SYM as neither disadvantaged nor advantaged.

[6] To avoid influencing decisions in the experiment, subjects were informed about the payment of a participation fee only at the end of the session, and the amounts were communicated privately.

[7] We also analyse equilibrium behaviour when agents have inequity-averse preferences as in Fehr and Schmidt (1999). Such preferences do not always generate unique equilibrium predictions, and the rankings of efforts can depend on the parameter values used. Hoffmann and Kolmar (2017) provide a thorough analysis of distributional preferences in both probabilistic and share contests under asymmetric abilities, suggesting that multiple asymmetric equilibria may exist. In Appendix B we show that this may be true under all three types of asymmetries.

Table 2. Equilibrium predictions: per-round efforts and expected earnings

	Efforts			Expected Earnings			Earnings Ratio
Treatment	**Disadv.**	**Adv.**	**Pair**	**Disadv.**	**Adv.**	**Pair**	**Disadv./Adv.**
SYM	20		40	115		230	-
ASYM-E	20	20	40	100	140	240	0.71
ASYM-A	15	15	30	100	140	240	0.71
ASYM-V	7.5	22.5	30	97.5	162.5	260	0.60

Disadv. = Disadvantaged players; Adv. = Advantaged players.

Our chosen parameters generate clear predictions for treatment comparisons under standard game-theoretic assumptions, either for effort or expected payoffs. Predicted total effort under risk neutrality is the same in SYM and ASYM-E, and in ASYM-A and ASYM-V. The latter two types of asymmetry differ in only the distribution of equilibrium effort between advantaged and disadvantaged players. Further, total expected earnings are equal in ASYM-A and in ASYM-E. Here, predicted equilibrium efforts of both types of players are symmetric in both treatments, although they are lower in ASYM-E. Nevertheless, expected earnings are held constant, thus providing a clear treatment comparison.

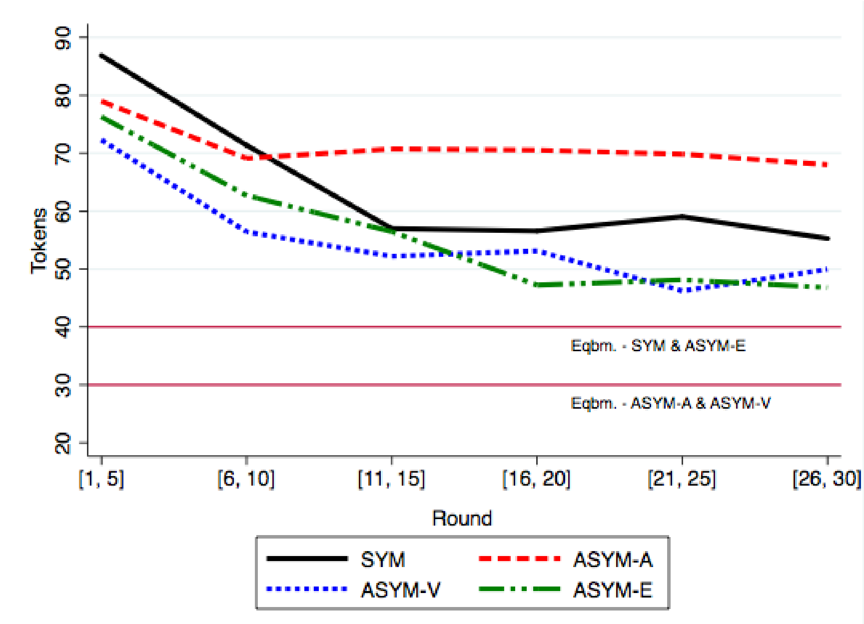
4. Results

Our analysis is organized around the testing of the rankings of observed efforts implied by the Nash equilibrium predictions. Unless otherwise stated, we use Wilcoxon ranksum (RS) tests when making comparisons between treatments, and Wilcoxon signrank (SR) tests when making comparisons within treatments. A unit of observation is the effort in a pair (either total or by each player type), averaged across all 30 rounds, thus leading to one independent observation per competing pair. Reported p-values are for two-sided tests.

4.1 Efforts

Figure 1 presents average efforts across time by competing pairs. In all treatments, efforts start high, decline over time and then stabilize in the second half. However, average efforts remain above the equilibrium predictions throughout the experiment in all treatments. This is a common finding in this type of experiments (e.g., Abbink et al., 2010 and Fallucchi et al., 2013). In the initial few rounds, there appears to be little difference in average aggregate efforts across treatments. Although the level of effort is higher in SYM than in other treatments, on average 87 tokens in the first 5 rounds, it rapidly declines to below 60 tokens in the first half of the experiment. The smallest decline is observed in ASYM-A, where average efforts start at 78 tokens and do not fall below 68 tokens in later rounds. Average efforts in ASYM-E and ASYM-V start lower than the other treatments and stabilize at around 50 tokens in later rounds.

Figure 1. Average total effort in competing pairs over time.



Summary statistics confirm the ranking of treatments observed in Figure 1: average efforts across all 30 rounds are highest in ASYM-A (71.20), followed by SYM (64.35) and then by ASYM-E (56.26) and ASYM-V (55.03). In all treatments efforts are significantly above equilibrium predictions (all SR $p < 0.008$).

Result 0: *Average efforts by competing pairs are higher than the equilibrium predictions in all treatments.*

Overall rent-seeking efforts by competing pairs are not significantly affected by the presence of asymmetry between competitors (RS $p > 0.10$ for all pairwise comparisons with the SYM treatment). However, average overall effort is greater in the presence of inequality in abilities than in the presence of either of the other two asymmetries: average efforts are significantly higher in ASYM-A than in ASYM-V (RS $p = 0.021$) and, weakly so relative to ASYM-E (RS $p = 0.087$).

Result 1: *Relative to efforts in the symmetric treatment, aggregate efforts are not different in the presence of asymmetries. However, aggregate efforts are higher in the presence of asymmetric abilities than other asymmetries.*

We next investigate if there are differences in behaviour between disadvantaged and advantaged players. Figure 2 presents average individual efforts by disadvantaged (Fig. 2a) and advantaged (Fig. 2b) players across rounds.[8] Average individual efforts of disadvantaged players are higher than average efforts of advantaged players in ASYM-A. On the other hand, efforts of disadvantaged players in ASYM-V and ASYM-E are lower than those of their respective advantaged opponents throughout the experiment.

Figure 2. Average individual efforts over time by player type.

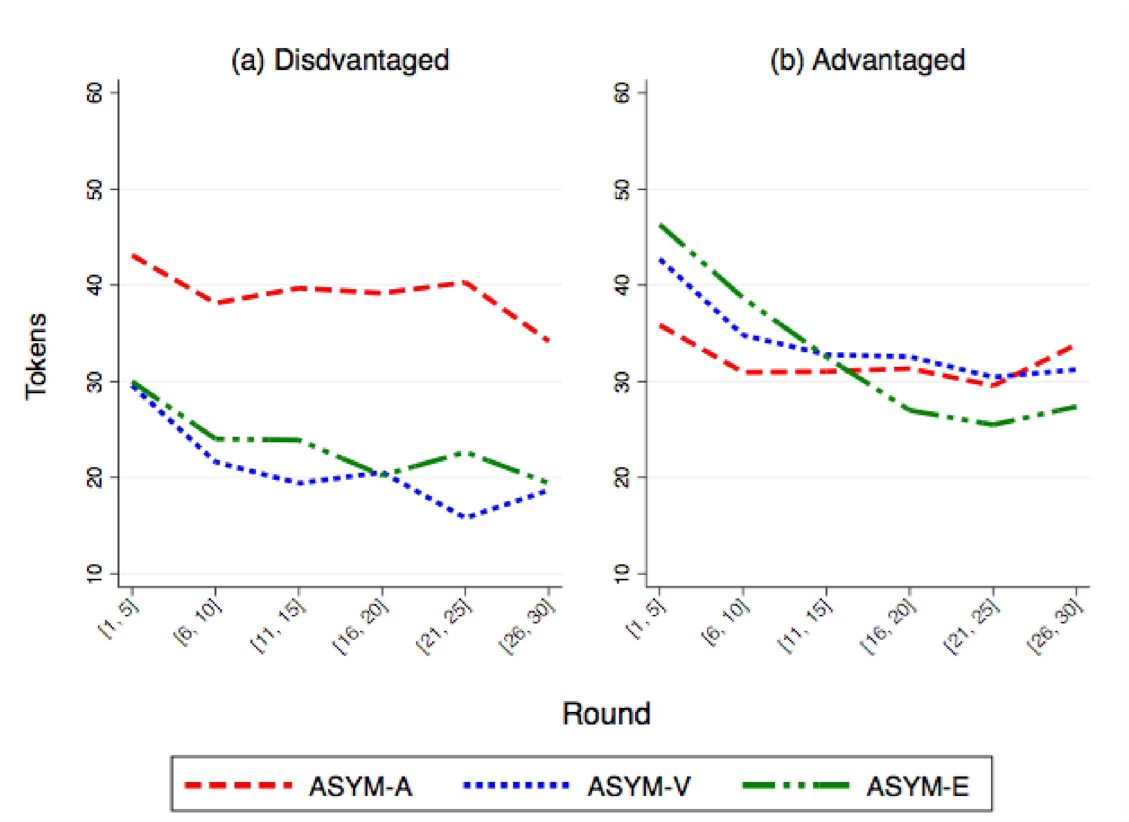


Table 3 reports, for each treatment, average (across all 30 rounds) individual efforts by the two player types. Efforts of disadvantaged players are significantly higher than those of advantaged players in ASYM-A (SR p = 0.049), while the opposite is true in ASYM-E (SR p = 0.010) and in ASYM-V (SR p < 0.001).

[8] We exclude SYM as subjects in this treatment are neither disadvantaged nor advantaged.

Table 3. Average per-round efforts: by player type.

Treatment	Obs.	Player type		
		Disadvantaged	Advantaged	Diff.
SYM	20	32.18		
		(13.87)		
ASYM-A	19	39.11	32.09	7.02
		(15.31)	(12.30)	
ASYM-V	20	20.94	34.09	-13.15
		(18.52)	(20.52)	
ASYM-E	20	23.37	32.90	-9.53
		(15.70)	(19.19)	

Obs. = No. of independent pairs in the treatment. Figures in parentheses are standard deviations.

Among the disadvantaged players, average efforts are highest in ASYM-A, and are almost twice the average efforts in ASYM-E and ASYM-V. Compared to efforts in SYM, efforts of disadvantaged players in ASYM-A are higher but not significantly different (RS p = 0.122), but efforts are significantly lower in ASYM-V (RS p = 0.017) and in ASYM-E (RS 0.062). Pairwise comparisons between asymmetric treatments confirm that disadvantaged subjects in ASYM-A are significantly more aggressive than in ASYM-V (RS p = 0.002) and ASYM-E (RS p = 0.004).

Unlike with disadvantaged players, average effort of advantaged players are remarkably close across treatments and range between 32.09 (ASYM-A) to 34.09 tokens (ASYM-V). None of the differences between the asymmetric treatments or versus SYM is statistically significant (RS p > 0.10 for all pairwise comparisons). However, from Figure 2(b), we notice a marked decrease in effort over time in ASYM-V and ASYM-E, but not in ASYM-A.

Result 2: *(a) Average effort of advantaged players are statistically indistinguishable across asymmetric treatments and from the efforts of symmetric players.*

(b) Asymmetry in ability leads to higher effort by disadvantaged players than their advantaged opponents, and higher effort than disadvantaged players in the other asymmetric treatments.

(c) Asymmetries in resources and prize valuations lead to lower effort by disadvantaged players compared to their advantaged opponents and symmetric players.

From the above findings, we infer that treatment differences are driven by the behaviour of disadvantaged players. However, the above reported aggregate tests present a rather cursory picture of behaviour, and thus of the influences of asymmetries. First, by aggregating across all

30 rounds, they do not capture the time dynamics evident in Figures 1 and 2. Second, they ignore the influence of past behaviour – both one's own and that of the other contestant.

To exploit the richness of our data, we estimate a set of multilevel panel mixed-effects tobit regressions that take into account the inter-dependence of individual players within a given contest. The dependent variable is a subject's effort in a round. In regression (1) the independent variables include a time trend, the subject's one-round lagged effort, the one-round lagged effort of his/her opponent, a dummy for whether the subject won the contest in the previous round and a dummy for each of the asymmetric treatments and their interactions with the one-round lagged effort of his/her opponent (the reference treatment is SYM). In further regressions we analyse effort of the two player types relative to effort in the symmetric treatment (2 and 3). The regression estimates are presented in Table 4.

Table 4. Determinants of individual effort.

	All	Advantaged	Disadvantaged
	(1)	(2)	(3)
Own effort in previous round	0.294*** (0.016)	0.386*** (0.020)	0.259*** (0.021)
Indicator for win in previous round	-1.820*** (0.640)	-2.673*** (0.721)	-1.691* (0.865)
Round	-0.232*** (0.034)	-0.198*** (0.039)	-0.255*** (0.047)
ASYM-V dummy	-3.767 (2.950)	1.320 (2.670)	-10.187*** (3.833)
ASYM-E dummy	-4.262 (2.907)	-2.933 (2.710)	-6.749* (3.592)
ASYM-A dummy	4.489 (2.983)	1.704 (2.772)	8.722** (3.938)
Opponent's effort in previous round	0.169*** (0.028)	0.155*** (0.026)	0.178*** (0.031)
ASYM-V × opponent's effort	0.018 (0.044)	0.105** (0.049)	-0.020 (0.061)
ASYM-E × opponent's effort	0.038 (0.039)	0.170*** (0.049)	-0.037 (0.048)
ASYM-A × opponent's effort	-0.067* (0.038)	-0.039 (0.037)	-0.133** (0.067)
Constant	21.254*** (2.089)	18.676*** (1.916)	22.369*** (2.425)
Observations	4582	2871	2871

Notes: Mixed-effects tobit regressions with random intercepts at the individual and group level. Dependent variable: individual effort. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

In line with previous experimental evidence (see Dechenaux et al., 2015), all models find that the controls for own past behaviour and the time trend are statistically significant and of the right sign. Model (1) echoes the finding in Results 1 and 2 – pooling both player types, there are no significant differences in individual effort across treatments with respect to SYM.[9]

Further specifications confirm the similar magnitude of effort of advantaged players across treatments: the ranking of coefficients of ASYM-V and ASYM-E are in line with theoretical predictions, although none of these differ significantly from SYM (Model 2).[10] In all treatments, contestants tend to adjust their effort to the opponent's effort observed in the previous round. The interactions between opponent's lagged effort and the treatment dummies of ASYM-V and ASYM-E are positive and significant, suggesting that advantaged players in these treatments strongly adapt their behaviour to those of their opponents, more than in SYM. This is not true in ASYM-A, where the adjustment is significantly smaller than in the other asymmetric treatments.

Focusing on disadvantaged players, efforts are significantly higher in ASYM-A than in SYM (Model 3), while efforts are lower in both ASYM-V and ASYM-E. However, the behaviour of disadvantaged contestants in ASYM-V is not significantly different from those in ASYM-E.[11] Interestingly, compared to the symmetric treatment, in all asymmetric treatments disadvantaged players adapt less their behaviour to the past effort of the advantaged opponents. Interestingly, disadvantaged players in ASYM-A do not adapt their efforts to that of their opponents at all – the interaction between opponent's lagged effort and ASYM-A is negative and significant and almost cancels out the effect of the opponent's lagged effort variable.

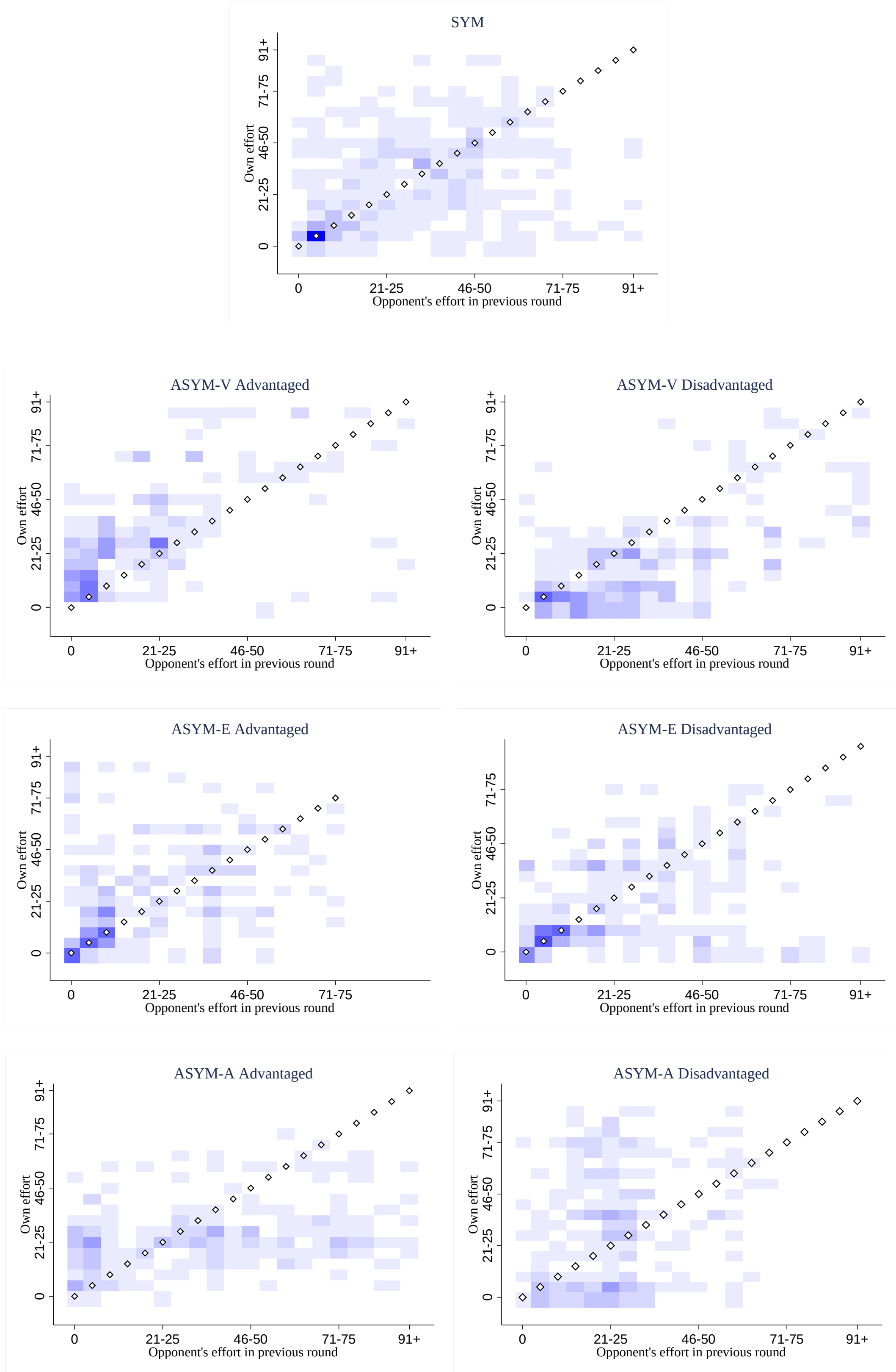
Further insights of this behaviour comes from Figure 3. We plot for each treatment and player type the heat map of effort choices based on the opponent's previous effort. In SYM we notice that most of choices lies around the match with previous opponent's choices. In ASYM-V and ASYM-E advantaged (disadvantaged) players either match or keep their efforts above (below) the one observed from their opponents in the previous round. In ASYM-A most effort choices by both players do not seem correlated with the effort previously exerted by the opponent.

[9] Post regression F-tests confirm that efforts are significantly higher in ASYM-A than in ASYM-V ($p = 0.004$) and ASYM-E ($p = 0.004$).

[10] An F-test fails to reject the null hypothesis of equality of ASYM-E and ASYM-V in Model 2 ($p > 0.284$).

[11] An F-test fails to reject the null hypothesis of equality of ASYM-E and ASYM-V in Model 3 ($p > 404$).

Figure 3. Heat maps of efforts (vertical axis) based on the opponent's effort observed in the previous round (horizontal axis) (last 15 rounds). Darker colours indicate a higher frequency.



The regressions and the heat maps thus provide additional insights into the differences in competitive efforts across types of asymmetries. In particular, we can draw a clear difference in behaviour between contestants in ASYM-A and those in other asymmetric settings. The difference is not only explained by the disadvantaged players under asymmetric ability being more aggressive, but also by the reaction that players have to their opponents' past choices. While neither of the two types adapts their choices to their opponents' past efforts in ASYM-A, advantaged and disadvantaged players in both ASYM-E and ASYM-V condition their efforts on those of their disadvantaged opponents.

4.2 Simple heuristics behind behaviour: the E/a rule

That players are less responsive to the efforts of their opponents in ASYM-A implies that players are not playing best responses to their opponents' actions. This suggests that behaviour is less strongly motivated by financial incentives in this treatment. To check this possibility, we estimate the 'rationality' parameters of the Quantal Response Equilibrium (QRE) model of McKelvey and Palfrey (1995) for each treatment.[12]

We estimate the QRE model where the probability that a particular action is chosen is the same across rounds, but may differ between the two player types in each treatment with asymmetry. Since it is infeasible to calculate the QRE probabilities for each of the permitted choices, we group expenditures in *K* bins that depend on the strategy space of each player type. To do this we take multiples of 10 tokens starting from 5 to form 10 bins in case of SYM, ASYM-A and ASYM-V and 8 (12) bins for the disadvantaged (advantaged) player in ASYM-E, and round all choices to the closest bin. Let $\rho(x_{ik})$ be the probability that a player *i* chooses the k^{th} bin x_k. Let $E_\rho[\pi(x_{ik})]$ denote the expected payoff to a player i from choosing bin x_k given that the opponent plays the mixed strategy ρ over the *K* bins. For a given 'rationality' parameter $\lambda \in [0, \infty)$, the QRE probabilities are given by the solution to the $K_i + K_j$ equations:

$$\rho(x_{ik}) = \frac{e^{\lambda E_\rho[\pi(x_{ik})]}}{\sum_{l=1}^{K} e^{\lambda E_\rho\left[\pi(x_{jl})\right]}}$$

[12] The QRE has been previously employed to explain behaviour in contests. Lim et al. (2014) find that the size of mistakes increases with group size. Also, Chowdhury et al. (2014) find noisier behaviour in the standard lottery contest than in the payoff equivalent share contest, where subjects receive a share of the prize proportional to their effort. These findings can be justified by the tougher environments driven by a higher number of competitors or by a stochastic payoff mechanism of the lottery rather than a deterministic one.

For $\lambda = 0$ the solution is $\rho(x_{ik}) = 1/K$, i.e., choices are uniformly distributed over the strategy space for each player type. As $\lambda \to \infty$ the Quantal Response Equilibrium prediction converges to the Nash Equilibrium. Note that a smaller λ indicates more variability in behaviour.

We use Gambit (McKelvey et al., 2015) to compute the probabilities and the lambdas. We then calculate the log-likelihoods and perform a grid search to find the lambdas that best fit our data. We pool the last 15 rounds to avoid early-round adjustments due to learning. In Table 5 we report the estimated lambdas (measuring expected payoffs in pence), the respective log-likelihoods, the expected log-likelihood in case of a uniform distribution of choices, the estimated maximum log-likelihood in case of an exact match between the model predictions and the empirical distribution. From the estimated log-likelihoods we compute the goodness of fit of our data following Lim et al. (2014). We define Q as

$$Q = \frac{logL - logL_{UNIFORM}}{logL_{MAXIMUM} - logL_{UNIFORM}}.$$

Q ranges between 0, when the best fit is given by the uniform distribution, and 1, when the model perfectly predicts the empirical distribution.

Table 5. Quantal Response Equilibrium rationality parameter estimates.

Treatment	λ	Log-L	Uniform Log-L	Maximum Log-L	Q
SYM	0.178	-1,242.66	-1,381.55	-1,199.56	0.763
ASYM-V	0.205	-1,181.26	-1.381.55	-1,118.81	0.762
ASYM-E	0.185	-1,205.47	-1,369.31	-1,141.40	0.719
ASYM-A	0.106	-1,237.12	-1,312.47	-1,116.68	0.386

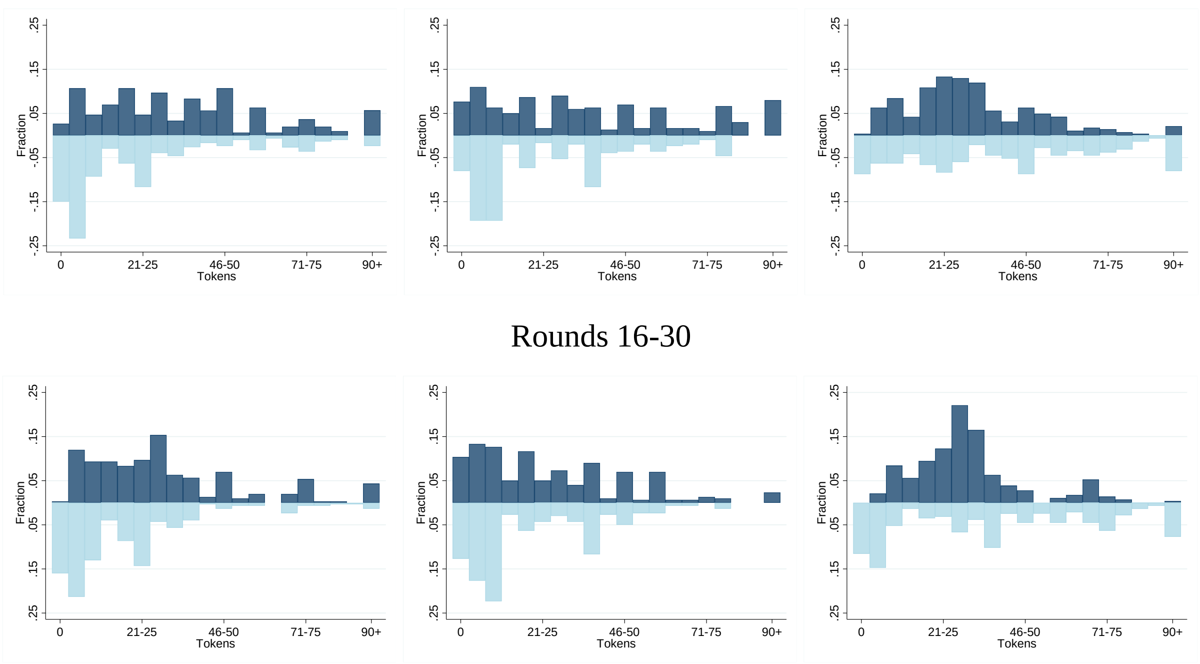
Results in Table 5 show a similar level of noise in SYM ($\lambda = 0.178$) and between the treatments with asymmetries in resources and prize valuations (λ = 0.185 and 0.205, respectively). Also, the goodness of fit of our data is similar across these treatments (Q ranges between 0.719 and 0.763). Therefore, lack of differences in individual behaviour among SYM, ASYM-E and ASYM-V can be explained by a similar level of noise across these treatments.

However, we find a significantly lower level of rationality in ASYM-A ($\lambda = 0.106$) compared to other treatments. Together with a lower λ we also find a worse fit of the empirical distribution with the data ($Q = 0.386$). Hence, the QRE estimation suggests that efforts in competition in the presence of a biased procedure are less strongly motivated by financial incentives.[13]

The results from Table 4 and the QRE estimations suggest two plausible behaviours adopted by contestants in ASYM-A: they either stick to a suboptimal choice or randomize over the entire strategy space. We examine the distribution of efforts in Figure 4 to see if there is any indication of either type of behaviour in ASYM-A. We report in dark (light) blue the distribution of efforts by the advantaged (disadvantaged) players for each treatment. We compare behaviour in the first and the last 15 rounds.

Figure 4. Histograms of efforts in the first and last 15 rounds in the asymmetric treatments. Dark blue bars indicate fractions of the advantaged players, light blue bars those of disadvantaged players. The first bar represents the fraction of 0 efforts.

Rounds 1-15



(a) ASYM-V (b) ASYM-E (c) ASYM-A

[13] For between-treatment comparisons we pool the data from both treatments and estimate a single lambda parameter, and compare the resulting log-likelihood with the sum of the log-likelihoods from estimating separate lambda parameters for the separate treatments. Under the null hypothesis that lambda is the same across treatments, the statistic $D(between\ treatments) = -2\left[log\hat{L}_{Pooled} - (log\hat{L}_{treatment-1} + log\hat{L}_{treatment-2})\right]$ is asymptotically distributed as χ^2 with 1 degree of freedom. Pairwise comparisons between ASYM-A and other treatments show a significant decrease in the noise parameter lambda (all p < 0.001).

The distribution of efforts differs notably across treatments and types. In ASYM-V (a) and ASYM-E (b), efforts are similarly dispersed in the first 15 rounds and mostly concentrated in the first half of the strategy space in the last 15 rounds. Hence, in both treatments both types of players reduce efforts over time. Contestants in ASYM-A play the game very differently. Effort choices of disadvantaged players are distributed all across the strategy space, with a non-negligible fraction (10%) above the prize value, and do not differ much across the two halves of the game. The advantaged players, on the other hand, adjust their effort overt time. In the second part of the game the modal effort interval of the advantaged players is 26-30 tokens, and the majority of efforts lie in a small interval around the modal class (60% between 21 and 35 tokens).

This suggests that advantaged players in ASYM-A adopt a clear strategy. By consistently choosing an effort around 30 tokens (≈ endowment divided by the ability parameter), they secure a higher probability of winning each contest than their disadvantaged counterpart. Moreover, this is so regardless of the effort level of their disadvantaged opponent, as long as it is a rational choice. It is only by an effort above the prize value that the latter can get close to an equal chance of winning the prize. The advantaged players seem to understand this and anchor their choices around this value (we label this as the E/a rule). This strategy seems dictated by a response to the behaviour of the disadvantaged counterparts who, from early periods, adopt a "guerrilla warfare" type of strategy (Chowdhury et al., 2013), switching unpredictably from high effort in some contests and low (or none) in others.[14]

We believe that further evidence of the heuristic adopted by the advantaged players can be gathered from previous studies. In Fonseca (2009) where the endowment is 300 ECU, the prize is 200 ECU and the ratio of abilities is 7/3, the modal intervals of efforts of advantaged players are around 100 ECU (33% between 81 and 120). In Rockenbach and Waligora (2016), where the endowment is equal to the prize of 20 ECU, the distribution of efforts is modal at 5 ECU when the ability ratio is equal to 4 and bimodal at 5 ECU and 10 ECU when the ability ratio is equal to 2. Even with the lower ratio of 1.5 which would require effort of 15 ECU for the advantaged to be certain of an advantage, this choice is much more frequent than in other treatments, and the distribution of efforts has a longer tail. Similar to our findings, in all these cases, the disadvantaged players exhibit a more volatile strategy than their opponents.

[14] Both the strategies of advantaged and advantaged players in ASYM-A are common to most of the individuals (see boxplots of individual efforts in the last 15 rounds in Appendix C).

Result 3: *(a) In contests with asymmetric abilities financial incentives seem to play a smaller role compared to the symmetric and other asymmetric contests.*

(b) Advantaged players in contests with asymmetric abilities anchor their efforts to guarantee them an edge in the probability of winning over the disadvantaged counterparts. Disadvantaged players' effort choices tend to be extremely volatile and aggressive.

(c) In other asymmetric contests effort choices by the advantaged (disadvantaged) players are more (less) dispersed. The advantaged players adapt their choices to the opponents' previous choices rather than anchor to a particular strategy.

Given this behaviour, the suboptimal choices made by the advantaged players seem to be justified for the purpose. As shown in Table 6, the fraction of rounds where advantaged players have a greater than 50% chance of winning the contest is higher in ASYM-A than in the other asymmetric treatments. Therefore, as we show below, the volatile behaviour of disadvantaged players in ASYM-A comes at a significant cost to them.

Table 6. Fractions of probability of winning (advantaged players)

	Probability of winning (advantaged players)		
	<50%	50%	>50%
ASYM-A	0.135	0.018	0.847
ASYM-V	0.193	0.070	0.737
ASYM-E	0.330	0.123	0.547

4.3 Implications for earnings

Table 7 presents average per-round earnings by competing pairs, and by player type within pairs in the asymmetric treatments. Group earnings are highest in ASYM-V, followed by ASYM-E, SYM and then ASYM-A. Average per-round earnings are significantly below the equilibrium levels for pairs in all treatments (SR $p < 0.001$ for all comparisons). The table also shows that average earnings of disadvantaged players are lower than the earnings of advantaged players in all asymmetric treatments (SR $p < 0.001$ for all treatments).

Table 7. Average per-round earnings (tokens).

Treatment	Obs.	Pair	Player type Disadv.	Adv.	Earnings ratio
SYM	20	205.65 (27.73)	102.83 (13.87)		-
ASYM-E	20	223.74 (30.03)	91.97 (13.92)	131.77 (18.84)	0.70
ASYM-A	19	198.79 (23.07)	79.89 (10.73)	118.90 (15.93)	0.67
ASYM-V	20	229.1 (40.70)	86.99 (15.21)	142.11 (34.62)	0.61
Total		210.45 (52.12)			

Obs. = No. of independent pairs in the treatment. Figures in parentheses are standard deviations.

By design, earnings in treatments ASYM-E and ASYM-A are expected to be similar, while advantaged (disadvantaged) players in ASYM-V should earn the most (least). However, we find that advantaged and disadvantaged players in ASYM-A earn significantly less than do their counterparts in ASYM-E (RS p = 0.012 and 0.046, respectively). On the other hand, average earnings of disadvantaged players in ASYM-V are statistically indistinguishable from those in ASYM-E (RS p = 0.449), but are (weakly) significantly higher than in ASYM-A (RS p = 0.060). Similarly, while average earnings of advantaged players are highest in ASYM-V, this difference is statistically significant relative to ASYM-A (RS p = 0.011) but not ASYM-E (p = 0.144).[15]

Result 4*: (a) Disadvantaged players earn less than advantaged players in all asymmetric treatments.*

(b) Average earnings of both advantaged and disadvantaged players are lower under asymmetric ability than under asymmetric resources and prize valuations.

(c) Average earnings of both advantaged and disadvantaged players are similar under asymmetries in resources and in prize valuations, which are higher than under asymmetry in ability.

Finally, note that the average per-round earnings of disadvantaged players in ASYM-A (79.89 tokens) is lower than the per-round endowment that they receive. This difference is statistically

[15] Note also that the average ratio of final earnings of disadvantaged to advantaged players is 0.67, 0.61 and 0.70 in ASYM-A, ASYM-V and ASYM-E, respectively. The final earnings ratio are remarkably close to the predicted earnings ratios presented in Table 3.

significant (SR $p < 0.001$). Disadvantaged players in ASYM-V also earn significantly less than their endowment (SR $p = 0.04$). However, as shown above, even they earn more than disadvantaged players in ASYM-A. All other player types earn significantly more than their endowments. Thus, players with a disadvantage in ability are particularly hurt by their choices; their efforts make them significantly worse off than not competing at all.

5. Discussion and conclusion

We examine the effects of three different sources of asymmetry on behaviour in two-player Tullock contests. Our results show that the type of asymmetry has considerable implications for the level of effort. In contrast with standard predictions, we find that asymmetry in opportunity to affect outcomes (for the same level of effort) leads to a higher level of effort than in symmetric contests or other contests with an unequal distribution of initial wealth or prize valuation. The QRE estimations suggest that financial incentives play a similar role in the symmetric treatment and under asymmetries in resources and prizes. However, financial incentives may play a smaller role in contests with asymmetric abilities.

We contribute to further understanding subjects' competitive behaviour. Our results suggest that the source of asymmetry critically affects the picture of how the competition unfolds. With asymmetry in prize valuations, perhaps unsurprisingly, effort by disadvantaged players is lower relative to the symmetric case. However, the higher prize value does not lead to an increase of effort by advantaged subjects. It is instead more surprising that there exists a similar gap in effort by player types with inequality in resource endowments, where theory predicts no differences. In both these cases, advantaged players seem to adapt their effort over time to that of their disadvantaged opponents.

We believe that the results from our experiment allow us further insight on the role of emotions in competitive settings. Empirical evidence from the field strongly supports the idea that subjects have a non-pecuniary utility from winning, the so called 'joy of winning' (Parco et al., 2005; Sheremeta, 2010), and that this contributes to the over-dissipation of rent in contests. So far this has been modelled as a constant that is added to the contestant's monetary prize. In a related tournament setting, Kräkel (2008) introduces a more realistic assumption whereby the utility (disutility) from winning (losing) depends on the difference in abilities between contestants. If the difference in ability between the two players is not large, then emotions will offset eventual discouragement and lead to higher competitiveness. Our experiment confirms this hypothesis for the difference in ability.

Moreover, the analysis of individual behaviour suggests that subjects strongly prefer to adapt to the choices of their opponents in a myopic way. Although this is a common result in symmetric contest experiments (see Dechenaux et al., 2015), our results show that such behaviour is common in asymmetric settings as well.

However, advantaged subjects tend to preserve their advantage in the expected probability of winning the contest over their opponents. Our results suggest that players with advantage in abilities focus on the minimum effort necessary to secure them an edge in the contest. This is because they can hardly form beliefs about the behaviour of their counterparts. Their disadvantaged counterparts' efforts are very aggressive and volatile, in what appears to be an attempt to be as likely to win as the advantaged players in at least some of the contests. Their aggressive strategy comes at a significant cost – they would have earned more by not entering the contest, i.e., by not putting in *any* competitive effort at all.

Acknowledgements

The authors thank Miguel Fonseca, Miguel Angel Melendez-Jimenez, Anwesha Mukherjee, Zahra Murad, Daniele Nosenzo, Dmitry Ryvkin, Klaus Schmidt, Roman Sheremeta, Theodore Turocy, Bertil Tungodden and seminar participants at LISER and the 2016 ESA European Meetings at Bergen for helpful comments, suggestions and discussions. Funding from the School of Economics at the University of East Anglia is gratefully acknowledged. Fallucchi thanks the ESRC (NIBS Grant ES/K002201/1) for financial support.

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ELECTRONIC SUPPLEMENTARY MATERIAL

Inequality and Competitive Effort: The Roles of Asymmetric Resources, Opportunity and Outcomes

Francesco Fallucchi [a], Abhijit Ramalingam [b]

[a] LISER - Luxembourg

[b] Department of Economics, Walker College of Business, Appalachian State University, Boone, NC 28608, USA

Appendix A – Experimental Instructions

A.1 Instructions (SYM)

Welcome! You are about to take part in an experiment about decision-making. It is important that you do not talk to any of the other participants until the experiment is over. If you have a question at any time please raise your hand and an experimenter will come to your desk to answer it.

During the experiment you will have the chance to earn points, which will be converted into cash using an exchange rate of

35 points = 10p.

At the end of today's session you will be paid in private and in cash. The amount you earn will depend on your decisions and on the decisions of others, so please follow the instructions carefully.

At the beginning of the experiment you will be matched with one other person. The other person will be randomly selected from the participants in this room at the beginning of the experiment, and will stay the same throughout the whole experiment.

Note that you will not be informed of the identity of the other person, neither during, nor after today's session. Likewise, other participants will not be informed of your identity.

Decision task

The experiment will consist of **30 rounds**, and in each round you and the other player will compete for a prize, as will now be explained.

Each round has the same structure. **There are two types of players: BLUE players, and GREEN players**. At the beginning of each round each player will be given an endowment of **tokens. BLUE players get an endowment of 95 tokens, and GREEN players get an endowment of 95 tokens.**

If you are a **BLUE** player, the player you are matched will be a **GREEN** player, and vice versa. You will learn which player type you are (and therefore, the type of the other player) at the

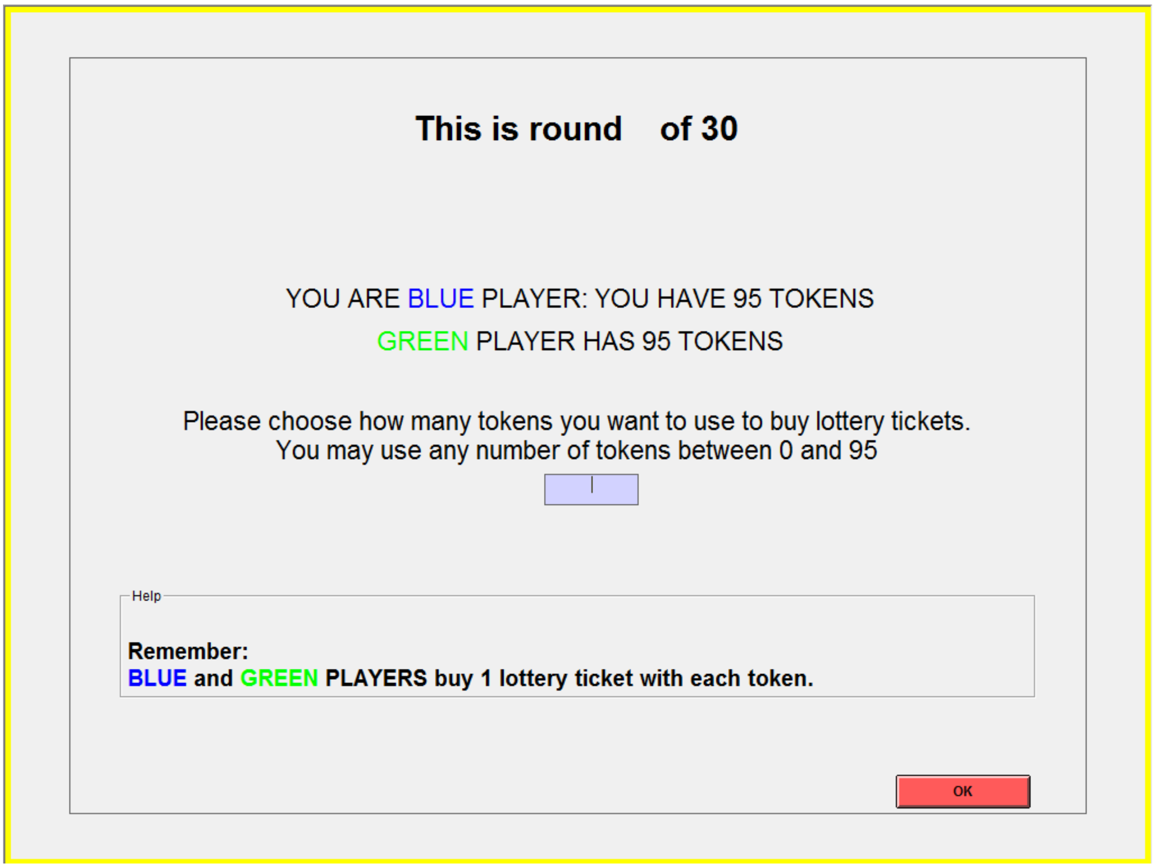
beginning of the experiment. Your player type (and the type of the other player) will remain the same throughout the experiment.

Each player can keep his/her tokens for himself/herself, or use them to buy “lottery tickets”, which determine your chance of winning a prize (more details below). BLUE player buys 1 BLUE lottery ticket with 1 token. Each GREEN player buys 1 GREEN lottery tickets with 1 token.

In other words, if you are a BLUE player you can buy between 0 and 95 BLUE lottery tickets; and if you are a GREEN player you can buy between 0 and 95 GREEN lottery tickets.

The tokens that are not used to buy lottery tickets are worth 1 point per token, **regardless of the player type**. These points will be added to the respective player’s point balance.

In each round each player must decide how many tokens to use to buy lottery tickets. Each participant will enter his or her decision via the computer. An example screenshot is shown below.



Determining the Winner of the Prize

Once everybody has made a decision in a round, the computer will calculate the total number of lottery tickets purchased by you and the other player you are matched with, and will determine which player wins the prize. The prize is worth **80 points**.

Once everybody has chosen how many lottery tickets to buy, the computer will determine which player in wins the prize by **randomly** selecting one of the tickets. The chance that you win the prize depends on the number of lottery tickets bought by you, and the number of lottery tickets bought by the other player. The exact chance of winning the lottery is given by the number of lottery tickets bought by you, divided by the total number of lottery tickets bought by both you and the other player. If you buy X lottery tickets and the other player buys Y lottery tickets, then your chance of winning the prize is $\frac{X}{X+Y}$, and the other player's chance of winning is $\frac{Y}{X+Y}$.

The computer will choose the winner by a random draw. Think of the random draw in terms of the computer choosing a ticket from a *hypothetical* box of different coloured tickets. To determine the winner, all the BLUE and GREEN tickets bought by you and the other player are put in the box. Then one ticket from the box is randomly chosen. If the chosen ticket is GREEN, the GREEN player wins the prize. If the chosen ticket is BLUE, the BLUE player wins the prize.

In general, the more lottery tickets you buy, the higher your chance of winning the lottery; the fewer lottery tickets you buy, the lower your chances of winning the lottery. The same applies for the other player.

Example:

1. If you purchase 60 lottery tickets and the other player purchases 60 lottery tickets, then the total number of lottery tickets is 120. Your chance of winning is $\frac{60}{120} = \frac{1}{2} = 50\%$. The other player's chance of winning is $\frac{60}{120} = \frac{1}{2} = 50\%$.
2. If you purchase 60 lottery tickets and the other player purchases 20 lottery tickets, then the total number of lottery tickets is 80.Your chance of winning is $\frac{60}{80} = \frac{3}{4} = 75\%$. The other player's chance of winning is $\frac{20}{80} = \frac{1}{4} = 25\%$.
3. If you purchase 20 lottery tickets and the other player purchases 60 lottery tickets, then the total number of lottery tickets is 80.Your chance of winning is $\frac{20}{80} = \frac{1}{4} = 25\%$. The other player's chance of winning is $\frac{60}{80} = \frac{3}{4} = 75\%$.

If both players do not buy any tickets, the prize is assigned randomly to one of the players.

Determining Payoffs

If you win the prize: you will earn points from the tokens you kept for yourself, and the prize.

$$Earnings = 95 - number\ of\ tokens\ used\ to\ purchase\ lottery\ tickets + \ the\ prize$$

If you do not win the prize: you will only earn points from the tokens you kept for yourself.

$$Earnings = 95 - number\ of\ tokens\ used\ to\ purchase\ lottery\ tickets$$

Example:

Suppose you

- Are BLUE player
- Receive 95 tokens
- Keep 75 tokens for yourself
- Use 20 tokens to purchase 20 BLUE lottery tickets (at a price of 1 ticket per token)

Suppose that the other player purchased a total of 60 GREEN lottery tickets. Remember that this means that this player used 60 tokens to get 60 GREEN lottery tickets.

Then, the chance that

- you win is $\frac{20}{20+60} = \frac{20}{80} = 0.25 = 25\%$
- and the chance that the other player wins is $\frac{60}{20+60} = \frac{60}{80} = 0.75 = 75\%$

Payoff

If a BLUE ticket is chosen, you win the prize:

You will earn 75 points from the 75 tokens you kept for yourself, and 80 points from the lottery, for a total of 155 points in the round.

$$Your\ payoff = 95 - 20 + 80 = 155$$

The other player will earn 35 points from the 35 tokens he/she kept for him/herself, and 0 points from the lottery, for a total of 35 points in the round.

$$Payoff\ of\ the\ other\ player = 95 - 60 + 0 = 35$$

If a GREEN ticket is chosen, you do not win the prize:

You will earn 75 points from the 75 tokens you kept for yourself, and nothing from the prize.

$$Your\ payoff = 95 - 20 = 75$$

The other player wins the prize and will earn 35 points from the 35 tokens he/she kept for him/herself, and 80 points from the lottery, for a total of 115 points in the round.

$$Payoff\ of\ the\ other\ player = 95 - 60 + 80 = 115$$

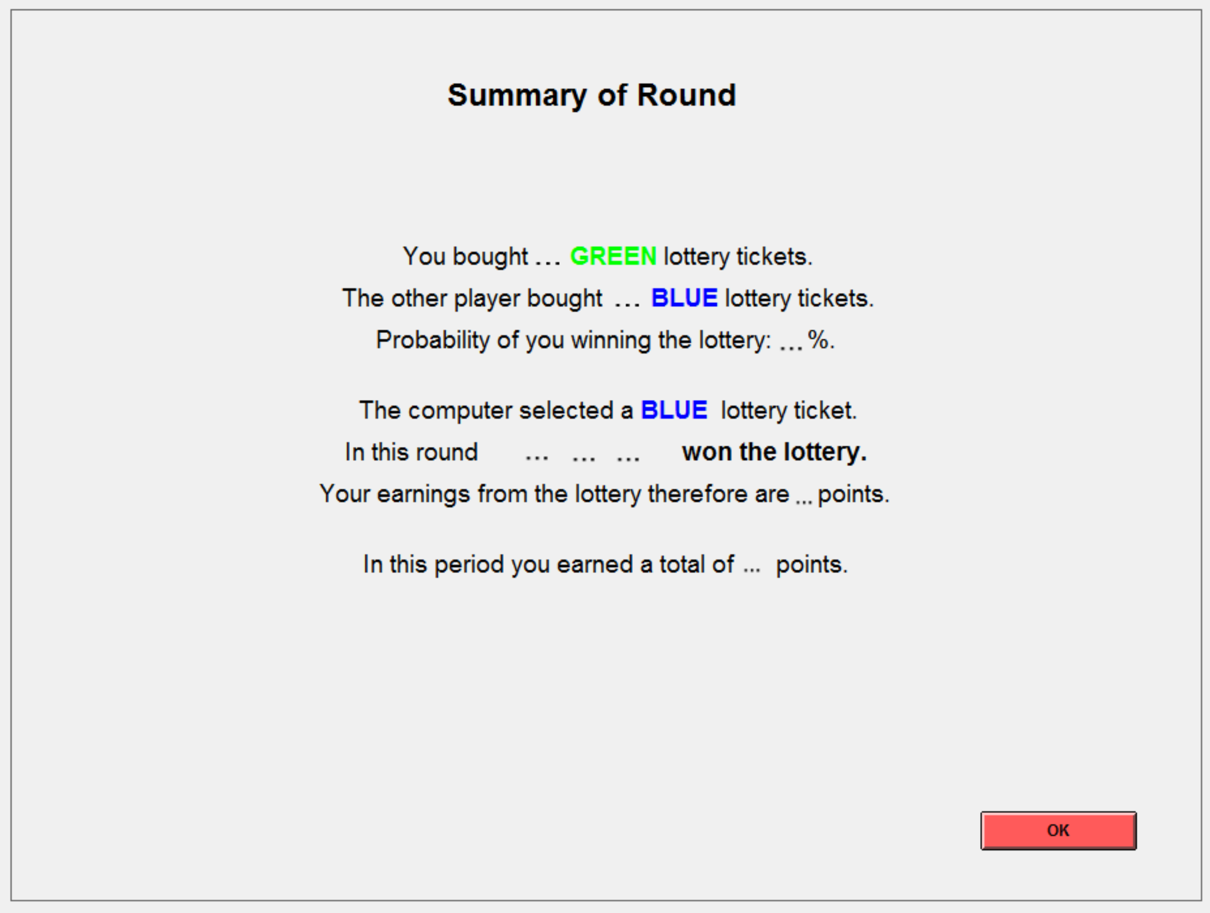
End of each round

After all participants have made a decision, a feedback screen will appear showing the results from the current round. You will receive the following summary of the round:

- Number of lottery tickets purchased by you
- Number of lottery tickets purchased by the other player
- The probability of you winning the lottery
- Which player won the prize
- Your earnings in this round

In addition, you will receive the above information for all previous rounds.

An example feedback screen:



The points you earn in each round will be added to the points you earned in the previous rounds, and at the end of the session you will be paid based on your total point earnings from all 30 rounds.

Beginning the experiment

If you have any questions please raise your hand and an experimenter will come to your desk to answer it.

Before starting the decision-making part of the experiment a set of questions will appear on your screen. These will help you to gain an understanding of the calculation of your earnings. Once everyone has answered these questions correctly, we will begin the experiment.

A2. Instructions (ASYM-A)

Welcome! You are about to take part in an experiment about decision-making. It is important that you do not talk to any of the other participants until the experiment is over. If you have a question at any time please raise your hand and an experimenter will come to your desk to answer it.

During the experiment you will have the chance to earn points, which will be converted into cash using an exchange rate of

35 points = 10p.

At the end of today's session you will be paid in private and in cash. The amount you earn will depend on your decisions and on the decisions of others, so please follow the instructions carefully.

At the beginning of the experiment you will be matched with one other person. The other person will be randomly selected from the participants in this room at the beginning of the experiment, and will stay the same throughout the whole experiment.

Note that you will not be informed of the identity of the other person, neither during, nor after today's session. Likewise, other participants will not be informed of your identity.

Decision task

The experiment will consist of **30 rounds**, and in each round you and the other player will compete for a prize, as will now be explained.

Each round has the same structure. **There are two types of players: BLUE players, and GREEN players**. At the beginning of each round each player will be given an endowment of **tokens. BLUE players get an endowment of 95 tokens, and GREEN players get an endowment of 95 tokens.**

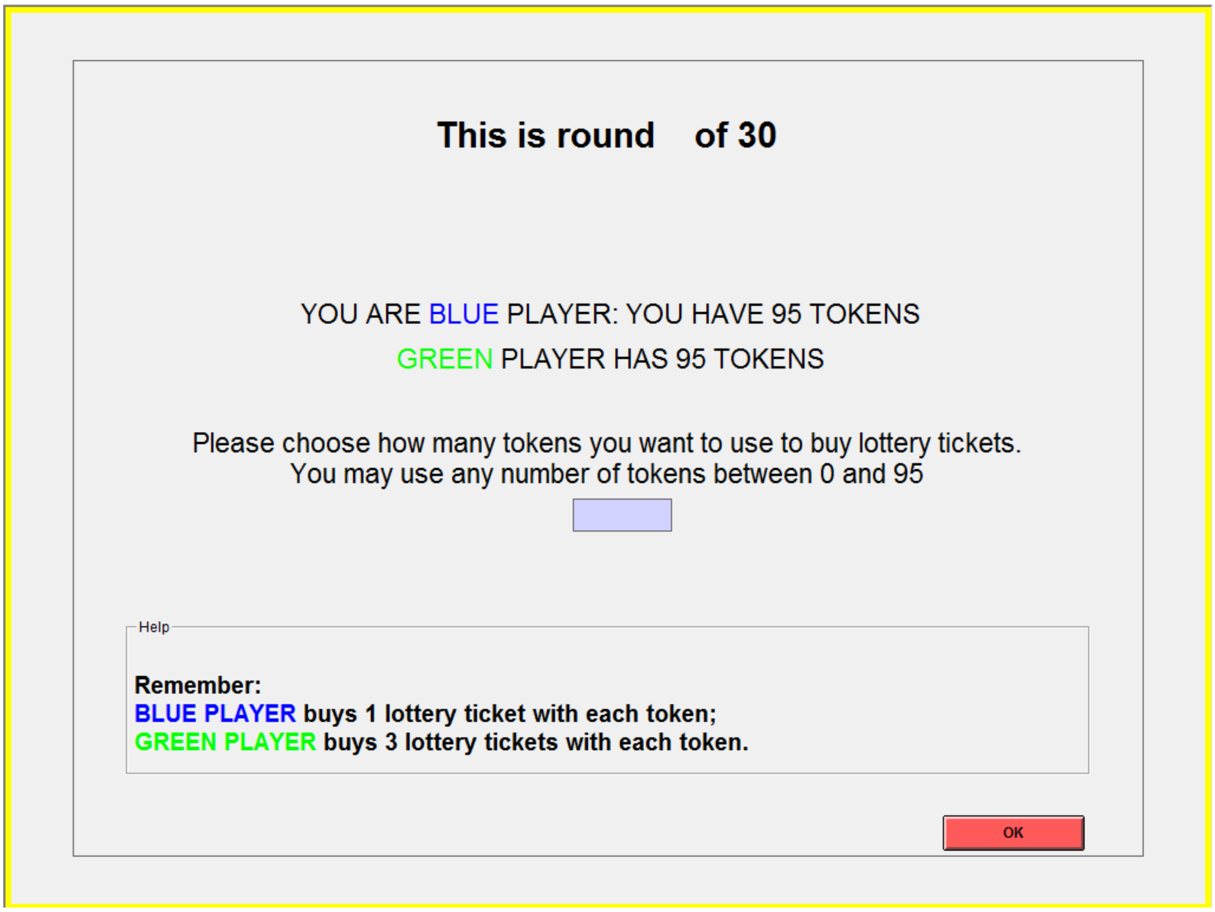
If you are a **BLUE** player, the player you are matched will be a **GREEN** player, and vice versa. You will learn which player type you are (and therefore, the type of the other player) at the beginning of the experiment. Your player type (and the type of the other player) will remain the same throughout the experiment.

Each player can keep his/her tokens for himself/herself, or use them to buy "lottery tickets", which determine your chance of winning a prize (more details below). BLUE player buys 1 BLUE lottery ticket with 1 token. Each GREEN player buys 3 GREEN lottery tickets with 1 token.

In other words, if you are a BLUE player you can buy between 0 and 95 BLUE lottery tickets; and if you are a GREEN player you can buy between 0 and 285 GREEN lottery tickets.

The tokens that are not used to buy lottery tickets are worth 1 point per token, **regardless of the player type**. These points will be added to the respective player's point balance.

In each round each player must decide how many tokens to use to buy lottery tickets. Each participant will enter his or her decision via the computer. An example screenshot is shown below.



Determining the Winner of the Prize

Once everybody has made a decision in a round, the computer will calculate the total number of lottery tickets purchased by you and the other player you are matched with, and will determine which player wins the prize. The prize is worth **80 points**.

Once everybody has chosen how many lottery tickets to buy, the computer will determine which player in wins the prize by **randomly** selecting one of the tickets. The chance that you win the prize depends on the number of lottery tickets bought by you, and the number of lottery tickets bought by the other player. The exact chance of winning the lottery is given by the number of lottery tickets bought by you, divided by the total number of lottery tickets bought by both you and the other player. If you buy X lottery tickets and the other player buys Y lottery tickets, then your chance of winning the prize is $\frac{X}{X+Y}$, and the other player's chance of winning is $\frac{Y}{X+Y}$.

The computer will choose the winner by a random draw. Think of the random draw in terms of the computer choosing a ticket from a *hypothetical* box of different coloured tickets. To determine the winner, all the BLUE and GREEN tickets bought by you and the other player are put in the box. Then one ticket from the box is randomly chosen. If the chosen ticket is GREEN, the GREEN player wins the prize. If the chosen ticket is BLUE, the BLUE player wins the prize.

In general, the more lottery tickets you buy, the higher your chance of winning the lottery; the fewer lottery tickets you buy, the lower your chances of winning the lottery. The same applies for the other player.

<u>Example:</u>

4. If you purchase 60 lottery tickets and the other player purchases 60 lottery tickets, then the total number of lottery tickets is 120. Your chance of winning is $\frac{60}{120} = \frac{1}{2} = 50\%$. The other player's chance of winning is $\frac{60}{120} = \frac{1}{2} = 50\%$.
5. If you purchase 60 lottery tickets and the other player purchases 20 lottery tickets, then the total number of lottery tickets is 80.Your chance of winning is $\frac{60}{80} = \frac{3}{4} = 75\%$. The other player's chance of winning is $\frac{20}{80} = \frac{1}{4} = 25\%$.
6. If you purchase 20 lottery tickets and the other player purchases 60 lottery tickets, then the total number of lottery tickets is 80.Your chance of winning is $\frac{20}{80} = \frac{1}{4} = 25\%$. The other player's chance of winning is $\frac{60}{80} = \frac{3}{4} = 75\%$.

If both players do not buy any tickets, the prize is assigned randomly to one of the players.

Determining Payoffs

If you win the prize: you will earn points from the tokens you kept for yourself, and the prize.

$$Earnings = 95 - number\ of\ tokens\ used\ to\ purchase\ lottery\ tickets + \ the\ prize$$

If you do not win the prize: you will only earn points from the tokens you kept for yourself.

$$Earnings = 95 - number\ of\ tokens\ used\ to\ purchase\ lottery\ tickets$$

Example:

Suppose you

- Are a BLUE player
- Receive 95 tokens
- Keep 75 tokens for yourself
- Use 20 tokens to purchase 20 BLUE lottery tickets (at a price of 1 ticket per token)

Suppose that the other player purchased a total of 60 GREEN lottery tickets. Remember that this means that this player used 20 tokens to get 60 GREEN lottery tickets.

Then, the chance that

- you win is $\frac{20}{20+60} = \frac{20}{80} = 0.25 = 25\%$
- and the chance that the other player wins is $\frac{60}{20+60} = \frac{60}{80} = 0.75 = 75\%$

Payoff

If a BLUE ticket is chosen, you win the prize:

You will earn 75 points from the 75 tokens you kept for yourself, and 80 points from the lottery, for a total of 155 points in the round.

$$Your\ payoff = 95 - 20 + 80 = 155$$

The other player will earn 75 points from the 75 tokens he/she kept for him/herself, and 0 points from the lottery, for a total of 75 points in the round.

$$Payoff\ of\ the\ other\ player = 95 - 20 + 0 = 75$$

If a GREEN ticket is chosen, you do not win the prize:

You will earn 75 points from the 75 tokens you kept for yourself, and nothing from the prize.

$$Your\ payoff = 95 - 20 = 75$$

The other player wins the prize and will earn 75 points from the 75 tokens he/she kept for him/herself, and 80 points from the lottery, for a total of 155 points in the round.

$$Payoff\ of\ the\ other\ player = 95 - 20 + 80 = 155$$

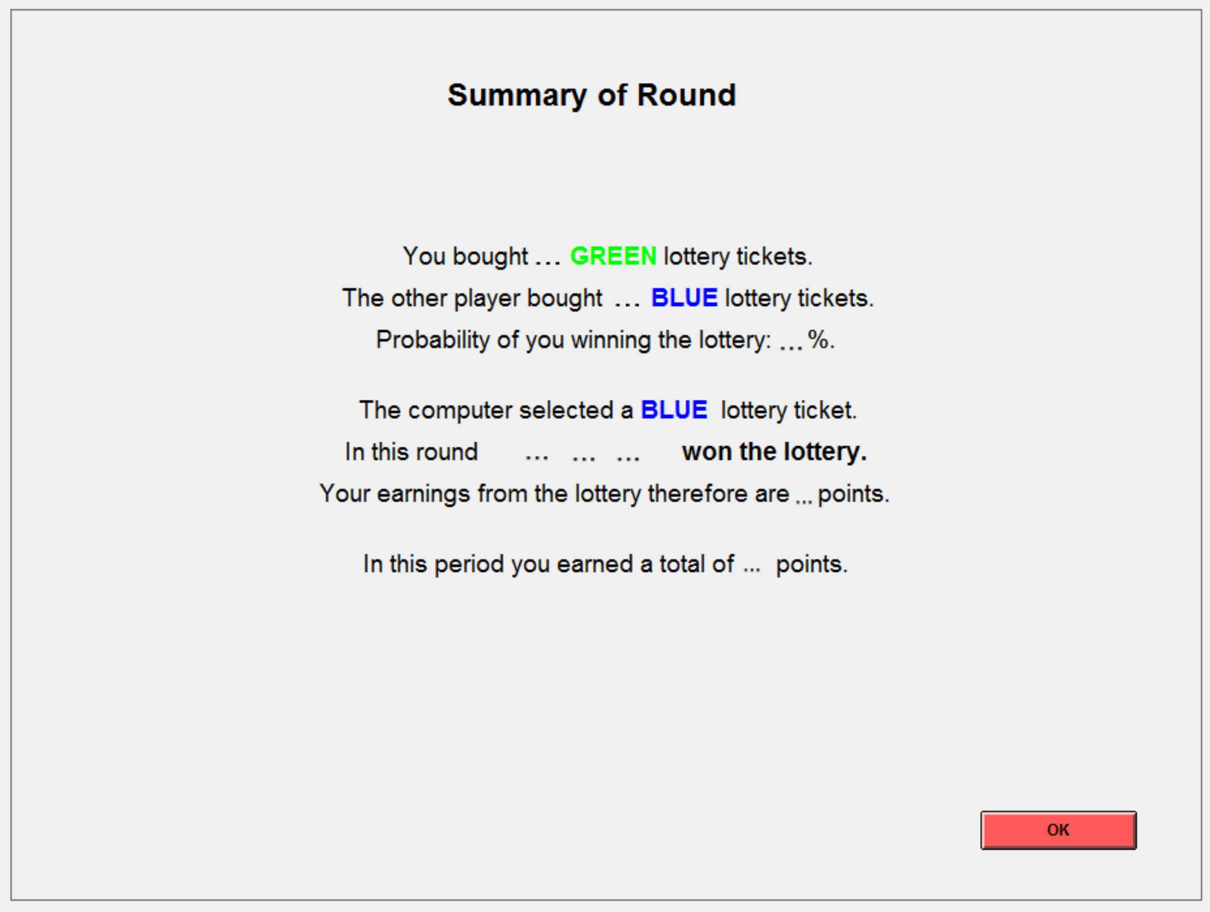
End of each round

After all participants have made a decision, a feedback screen will appear showing the results from the current round. You will receive the following summary of the round:

- Number of lottery tickets purchased by you
- Number of lottery tickets purchased by the other player
- The probability of you winning the lottery
- Which player won the prize
- Your earnings in this round

In addition, you will receive the above information for all previous rounds.

An example feedback screen:



The points you earn in each round will be added to the points you earned in the previous rounds, and at the end of the session you will be paid based on your total point earnings from all 30 rounds.

Beginning the experiment

If you have any questions please raise your hand and an experimenter will come to your desk to answer it.

Before starting the decision-making part of the experiment a set of questions will appear on your screen. These will help you to gain an understanding of the calculation of your earnings. Once everyone has answered these questions correctly, we will begin the experiment.

A3. Instructions (ASYM-E)

Instructions

Welcome! You are about to take part in an experiment about decision-making. It is important that you do not talk to any of the other participants until the experiment is over. If you have a question at any time please raise your hand and an experimenter will come to your desk to answer it.

During the experiment you will have the chance to earn points, which will be converted into cash using an exchange rate of

35 points = 10p.

At the end of today's session you will be paid in private and in cash. The amount you earn will depend on your decisions and on the decisions of others, so please follow the instructions carefully.

At the beginning of the experiment you will be matched with one other person. The other person will be randomly selected from the participants in this room at the beginning of the experiment, and will stay the same throughout the whole experiment.

Note that you will not be informed of the identity of the other person, neither during, nor after today's session. Likewise, other participants will not be informed of your identity.

Decision task

The experiment will consist of **30 rounds**, and in each round you and the other player will compete for a prize, as will now be explained.

Each round has the same structure. **There are two types of players: BLUE players, and GREEN players**. At the beginning of each round each player will be given an endowment of **tokens. BLUE players get an endowment of 80 tokens and GREEN players get an endowment of 120 tokens.**

If you are a **BLUE** player, the player you are matched will be a **GREEN** player, and vice versa. You will learn which player type you are (and therefore, the type of the other player) at the

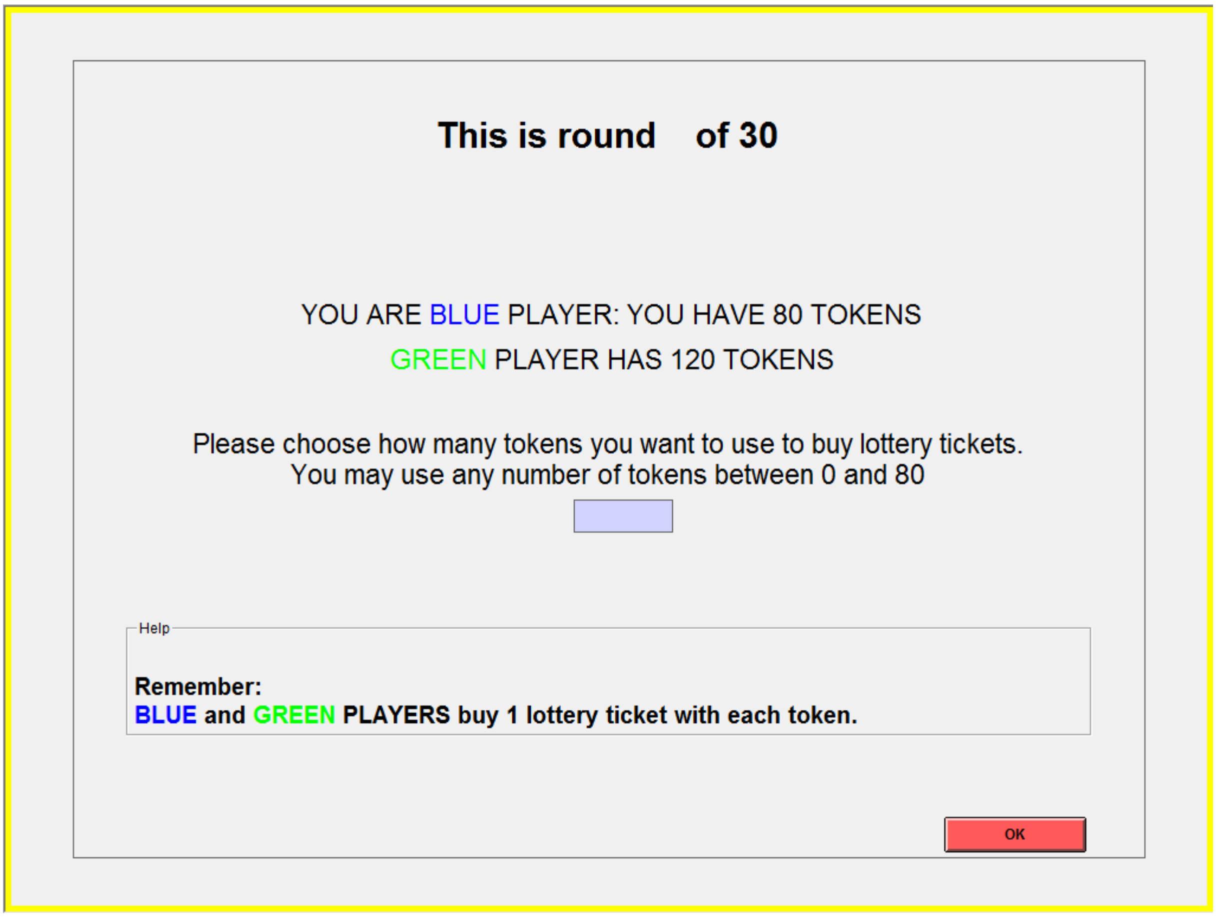
beginning of the experiment. Your player type (and the type of the other player) will remain the same throughout the experiment.

Each player can keep his/her tokens for himself/herself, or use them to buy “lottery tickets”, which determine your chance of winning a prize (more details below). BLUE player buys 1 BLUE lottery ticket with 1 token. Each GREEN player buys 1 GREEN lottery tickets with 1 token.

In other words, if you are a BLUE player you can buy between 0 and 80 BLUE lottery tickets; and if you are a GREEN player you can buy between 0 and 120 GREEN lottery tickets.

The tokens that are not used to buy lottery tickets are worth 1 point per token, **regardless of the player type**. These points will be added to the respective player’s point balance.

In each round each player must decide how many tokens to use to buy lottery tickets. Each participant will enter his or her decision via the computer. An example screenshot is shown below.



Determining the Winner of the Prize

Once everybody has made a decision in a round, the computer will calculate the total number of lottery tickets purchased by you and the other player you are matched with, and will determine which player wins the prize. The prize is worth **80 points**.

Once everybody has chosen how many lottery tickets to buy, the computer will determine which player in wins the prize by **randomly** selecting one of the tickets. The chance that you win the prize depends on the number of lottery tickets bought by you, and the number of lottery tickets bought by the other player. The exact chance of winning the lottery is given by the number of lottery tickets bought by you, divided by the total number of lottery tickets bought by both you and the other player. If you buy X lottery tickets and the other player buys Y lottery tickets, then your chance of winning the prize is $\frac{X}{X+Y}$, and the other player's chance of winning is $\frac{Y}{X+Y}$.

The computer will choose the winner by a random draw. Think of the random draw in terms of the computer choosing a ticket from a *hypothetical* box of different coloured tickets. To determine the winner, all the BLUE and GREEN tickets bought by you and the other player are put in the box. Then one ticket from the box is randomly chosen. If the chosen ticket is GREEN, the GREEN player wins the prize. If the chosen ticket is BLUE, the BLUE player wins the prize.

In general, the more lottery tickets you buy, the higher your chance of winning the lottery; the fewer lottery tickets you buy, the lower your chances of winning the lottery. The same applies for the other player.

<u>Example:</u>

7. If you purchase 60 lottery tickets and the other player purchases 60 lottery tickets, then the total number of lottery tickets is 120. Your chance of winning is $\frac{60}{120} = \frac{1}{2} = 50\%$. The other player's chance of winning is $\frac{60}{120} = \frac{1}{2} = 50\%$.
8. If you purchase 60 lottery tickets and the other player purchases 20 lottery tickets, then the total number of lottery tickets is 80.Your chance of winning is $\frac{60}{80} = \frac{3}{4} = 75\%$. The other player's chance of winning is $\frac{20}{80} = \frac{1}{4} = 25\%$.
9. If you purchase 20 lottery tickets and the other player purchases 60 lottery tickets, then the total number of lottery tickets is 80.Your chance of winning is $\frac{20}{80} = \frac{1}{4} = 25\%$. The other player's chance of winning is $\frac{60}{80} = \frac{3}{4} = 75\%$.

If both players do not buy any tickets, the prize is assigned randomly to one of the players.

Determining Payoffs

IF YOU ARE THE BLUE PLAYER

If you win the prize: you will earn points from the tokens you kept for yourself, and the prize.

$$Earnings = 80 - number\ of\ tokens\ used\ to\ purchase\ lottery\ tickets + \ the\ prize$$

If you do not win the prize: you will only earn points from the tokens you kept for yourself.

$$Earnings = 80 - number\ of\ tokens\ used\ to\ purchase\ lottery\ tickets$$

IF YOU ARE THE GREEN PLAYER

If you win the prize: you will earn points from the tokens you kept for yourself, and the prize.

$$Earnings = 120 - number\ of\ tokens\ used\ to\ purchase\ lottery\ tickets + \ the\ prize$$

If you do not win the prize: you will only earn points from the tokens you kept for yourself.

$$Earnings = 120 - number\ of\ tokens\ used\ to\ purchase\ lottery\ tickets$$

Example:

Suppose you

- Are BLUE player
- Receive 80 tokens
- Keep 60 tokens for yourself
- Use 20 tokens to purchase 20 BLUE lottery tickets (at a price of 1 ticket per token)

Suppose that the other player purchased a total of 60 GREEN lottery tickets. Remember that this means that this player used 60 tokens to get 60 GREEN lottery tickets.

Then, the chance that

- you win is $\frac{20}{20+60} = \frac{20}{80} = 0.25 = 25\%$
- and the chance that the other player wins is $\frac{60}{20+60} = \frac{60}{80} = 0.75 = 75\%$

Payoff

If a BLUE ticket is chosen, you win the prize:

You will earn 60 points from the 60 tokens you kept for yourself, and 80 points from the lottery, for a total of 140 points in the round.

$$Your\ payoff = 80 - 20 + 80 = 140$$

The other player will earn 60 points from the 60 tokens he/she kept for him/herself, and 0 points from the lottery, for a total of 60 points in the round.

$$Payoff\ of\ the\ other\ player = 120 - 60 + 0 = 60$$

If a GREEN ticket is chosen, you do not win the prize:

You will earn 60 points from the 60 tokens you kept for yourself, and nothing from the prize.

$$Your\ payoff = 80 - 20 = 60$$

The other player wins the prize and will earn 60 points from the 60 tokens he/she kept for him/herself, and 80 points from the lottery, for a total of 140 points in the round.

$$Payoff\ of\ the\ other\ player = 120 - 60 + 80 = 140$$

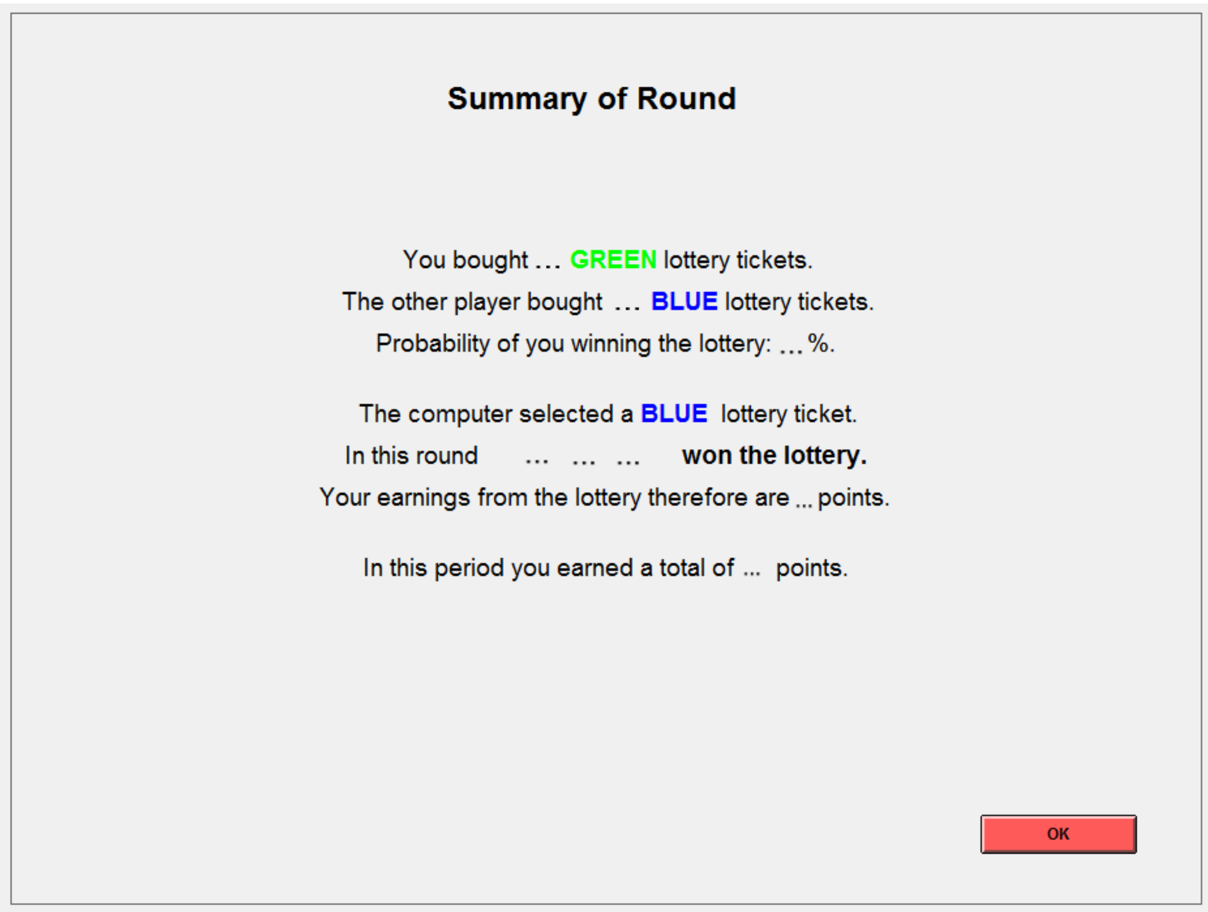
End of each round

After all participants have made a decision, a feedback screen will appear showing the results from the current round. You will receive the following summary of the round:

- Number of lottery tickets purchased by you
- Number of lottery tickets purchased by the other player
- The probability of you winning the lottery
- Which player won the prize
- Your earnings in this round

In addition, you will receive the above information for all previous rounds.

An example feedback screen:



The points you earn in each round will be added to the points you earned in the previous rounds, and at the end of the session you will be paid based on your total point earnings from all 30 rounds.

Beginning the experiment

If you have any questions please raise your hand and an experimenter will come to your desk to answer it.

Before starting the decision-making part of the experiment a set of questions will appear on your screen. These will help you to gain an understanding of the calculation of your earnings. Once everyone has answered these questions correctly, we will begin the experiment.

A4. Instructions (ASYM-V)

Instructions

Welcome! You are about to take part in an experiment about decision-making. It is important that you do not talk to any of the other participants until the experiment is over. If you have a question at any time please raise your hand and an experimenter will come to your desk to answer it.

During the experiment you will have the chance to earn points, which will be converted into cash using an exchange rate of

35 points = 10p.

At the end of today's session you will be paid in private and in cash. The amount you earn will depend on your decisions and on the decisions of others, so please follow the instructions carefully.

At the beginning of the experiment you will be matched with one other person. The other person will be randomly selected from the participants in this room at the beginning of the experiment, and will stay the same throughout the whole experiment.

Note that you will not be informed of the identity of the other person, neither during, nor after today's session. Likewise, other participants will not be informed of your identity.

Decision task

The experiment will consist of **30 rounds**, and in each round you and the other player will compete for a prize, as will now be explained.

Each round has the same structure. **There are two types of players: BLUE players, and GREEN players**. At the beginning of each round each player will be given an endowment of **tokens. BLUE players get an endowment of 95 tokens, and GREEN players get an endowment of 95 tokens.**

If you are a **BLUE** player, the player you are matched will be a **GREEN** player, and vice versa. You will learn which player type you are (and therefore, the type of the other player) at the

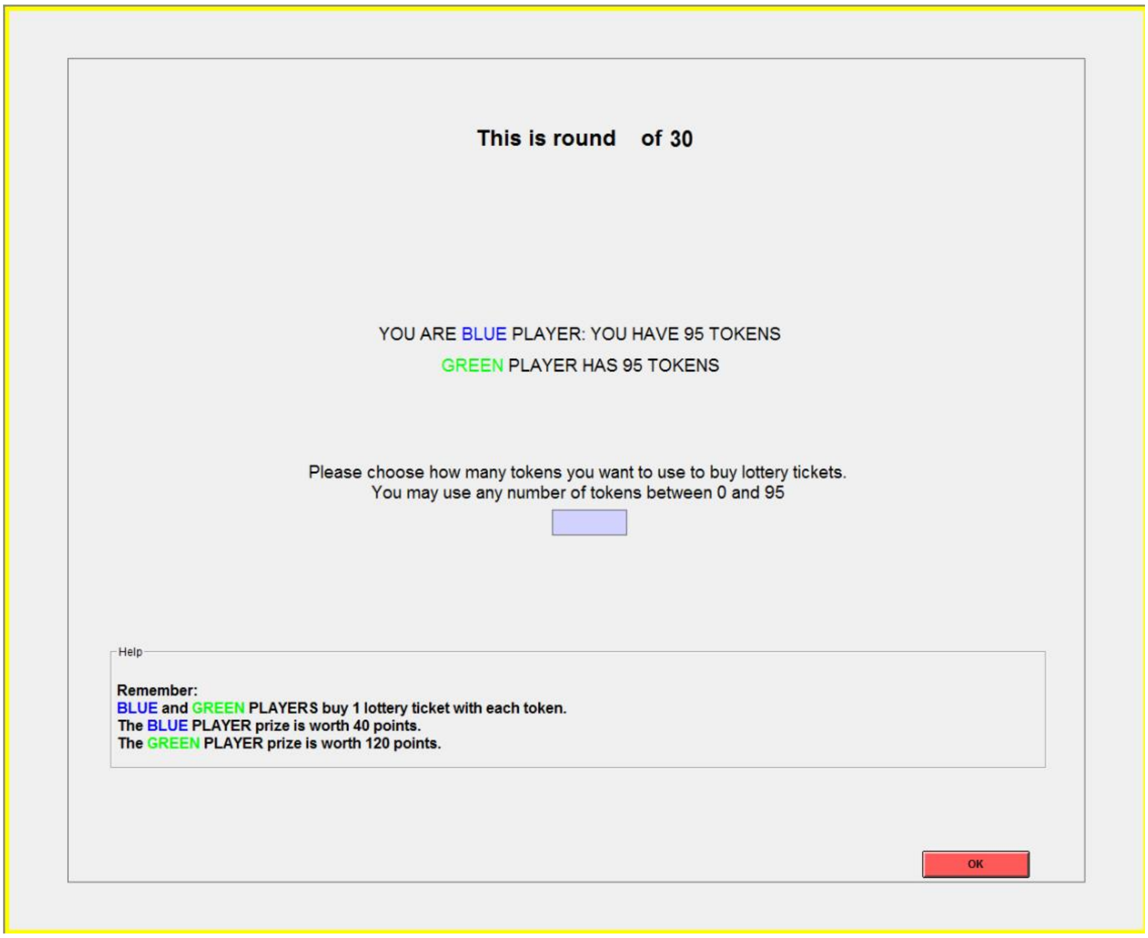
beginning of the experiment. Your player type (and the type of the other player) will remain the same throughout the experiment.

Each player can keep his/her tokens for himself/herself, or use them to buy “lottery tickets”, which determine your chance of winning a prize (more details below). Each BLUE player buys 1 BLUE lottery ticket with 1 token. Each GREEN player buys 1 GREEN lottery tickets with 1 token.

In other words, if you are a BLUE player you can buy between 0 and 95 BLUE lottery tickets; and if you are a GREEN player you can buy between 0 and 95 GREEN lottery tickets.

The tokens that are not used to buy lottery tickets are worth 1 point per token, **regardless of the player type**. These points will be added to the respective player’s point balance.

In each round each player must decide how many tokens to use to buy lottery tickets. Each participant will enter his or her decision via the computer. An example screenshot is shown below.



Determining the Winner of the Prize

Once everybody has made a decision in a round, the computer will calculate the total number of lottery tickets purchased by you and the other player you are matched with, and will determine which player wins the prize.

If you are a **BLUE** player: The prize is worth **40 points**.

If you are a **GREEN** player: The prize is worth **120 points**.

Once everybody has chosen how many lottery tickets to buy, the computer will determine which player in wins the prize by **randomly** selecting one of the tickets. The chance that you win the prize depends on the number of lottery tickets bought by you, and the number of lottery tickets bought by the other player. The exact chance of winning the lottery is given by the number of lottery tickets bought by you, divided by the total number of lottery tickets bought by both you and the other player. If you buy X lottery tickets and the other player buys Y lottery tickets, then your chance of winning the prize is $\frac{X}{X+Y}$, and the other player's chance of winning is $\frac{Y}{X+Y}$.

The computer will choose the winner by a random draw. Think of the random draw in terms of the computer choosing a ticket from a *hypothetical* box of different coloured tickets. To determine the winner, all the BLUE and GREEN tickets bought by you and the other player are put in the box. Then one ticket from the box is randomly chosen. If the chosen ticket is GREEN, the GREEN player wins the prize. If the chosen ticket is BLUE, the BLUE player wins the prize.

In general, the more lottery tickets you buy, the higher your chance of winning the lottery; the fewer lottery tickets you buy, the lower your chances of winning the lottery. The same applies for the other player.

<u>Example:</u>

10. If you purchase 60 lottery tickets and the other player purchases 60 lottery tickets, then the total number of lottery tickets is 120. Your chance of winning is $\frac{60}{120} = \frac{1}{2} = 50\%$. The other player's chance of winning is $\frac{60}{120} = \frac{1}{2} = 50\%$.
11. If you purchase 60 lottery tickets and the other player purchases 20 lottery tickets, then the total number of lottery tickets is 80. Your chance of winning is $\frac{60}{80} = \frac{3}{4} = 75\%$. The other player's chance of winning is $\frac{20}{80} = \frac{1}{4} = 25\%$.
12. If you purchase 20 lottery tickets and the other player purchases 60 lottery tickets, then the total number of lottery tickets is 80. Your chance of winning is $\frac{20}{80} = \frac{1}{4} = 25\%$. The other player's chance of winning is $\frac{60}{80} = \frac{3}{4} = 75\%$.

If both players do not buy any tickets, the prize is assigned randomly to one of the players.

Determining Payoffs

If you win the prize: you will earn points from the tokens you kept for yourself, and the prize.

$$Earnings = 95 - number\ of\ tokens\ used\ to\ purchase\ lottery\ tickets + the\ prize$$

If you do not win the prize: you will only earn points from the tokens you kept for yourself.

$$Earnings = 95 - number\ of\ tokens\ used\ to\ purchase\ lottery\ tickets$$

Remember:

If you are a **BLUE** player: The prize is worth **40 points**.

If you are a **GREEN** player: The prize is worth **120 points**.

Example:

Suppose you

- Are BLUE player
- Receive 95 tokens
- Keep 75 tokens for yourself
- Use 20 tokens to purchase 20 BLUE lottery tickets (at a price of 1 ticket per token)

Suppose that the other player purchased a total of 60 GREEN lottery tickets. Remember that this means that this player used 60 tokens to get 60 GREEN lottery tickets.

Then, the chance that

- you win is $\frac{20}{20+60} = \frac{20}{80} = 0.25 = 25\%$
- and the chance that the other player wins is $\frac{60}{20+60} = \frac{60}{80} = 0.75 = 75\%$

Payoff

If a BLUE ticket is chosen, you win the prize:

You will earn 75 points from the 75 tokens you kept for yourself, and 40 points from the lottery, for a total of 115 points in the round.

$$Your\ payoff = 95 - 20 + 40 = 115$$

The other player will earn 35 points from the 35 tokens he/she kept for him/herself, and 0 points from the lottery, for a total of 35 points in the round.

$$Payoff\ of\ the\ other\ player = 95 - 60 + 0 = 35$$

If a GREEN ticket is chosen, you do not win the prize:

You will earn 75 points from the 75 tokens you kept for yourself, and nothing from the prize.

$$Your\ payoff = 95 - 20 = 75$$

The other player wins the prize and will earn 35 points from the 35 tokens he/she kept for him/herself, and 120 points from the lottery, for a total of 155 points in the round.

$$Payoff\ of\ the\ other\ player = 95 - 60 + 120 = 155$$

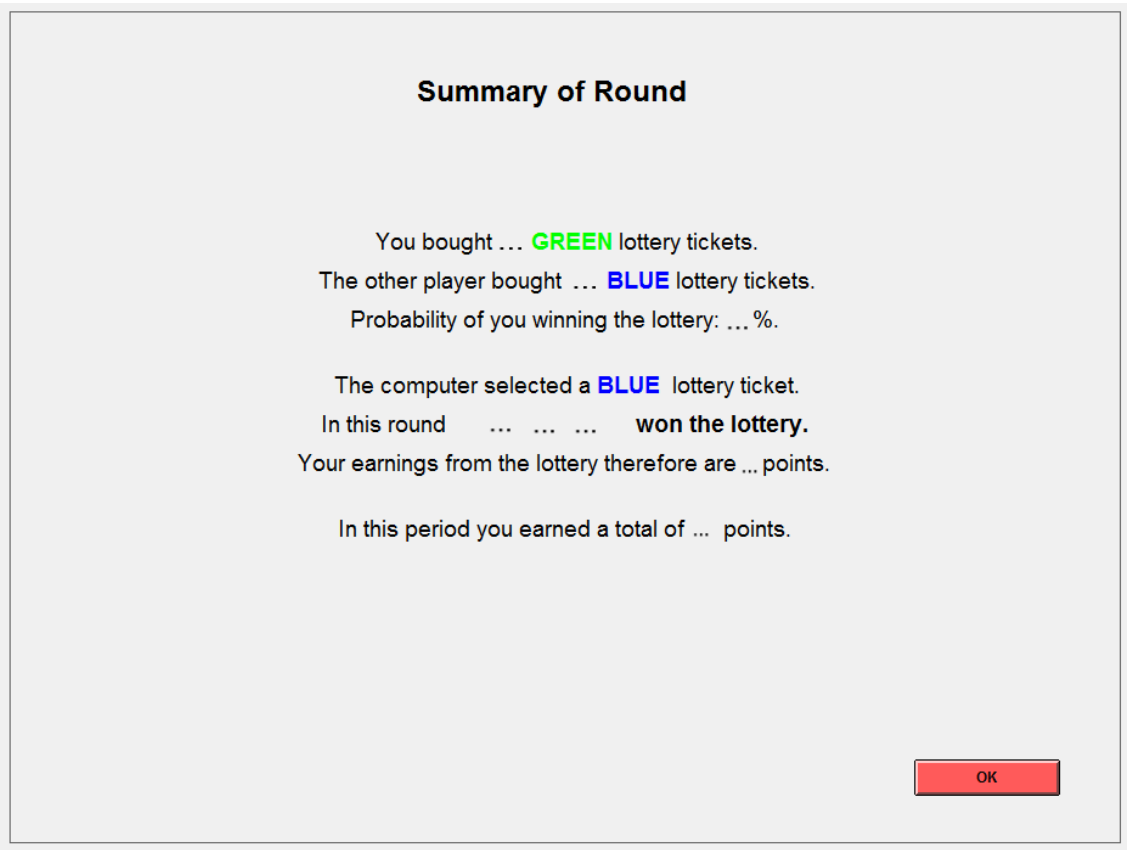
End of each round

After all participants have made a decision, a feedback screen will appear showing the results from the current round. You will receive the following summary of the round:

- Number of lottery tickets purchased by you
- Number of lottery tickets purchased by the other player
- The probability of you winning the lottery
- Which player won the prize
- Your earnings in this round

In addition, you will receive the above information for all previous rounds.

An example feedback screen:



The points you earn in each round will be added to the points you earned in the previous rounds, and at the end of the session you will be paid based on your total point earnings from all 30 rounds.

Beginning the experiment

If you have any questions please raise your hand and an experimenter will come to your desk to answer it.

Before starting the decision-making part of the experiment a set of questions will appear on your screen. These will help you to gain an understanding of the calculation of your earnings. Once everyone has answered these questions correctly, we will begin the experiment.

Appendix B – Inequality-averse preferences in asymmetric contests

A few studies consider Fehr and Schmidt (1999) preferences (henceforth F&S) of inequality-aversion to explain over-dissipation of rent compared to Nash equilibrium predictions. In the two-player variant of this model the utility of player i is given by

$$U_i = \pi_i - \alpha_i \, max(\pi_j - \pi_i, 0) - \beta_i \, max(\pi_i - \pi_j, 0), \qquad i = 1, 2; i \neq j$$

where π_i and π_j denote the players' monetary payoffs, α_i denotes the strength of aversion to disadvantageous inequality, i.e. the disutility of a subject on being behind her rival in terms of payoffs, and β_i denotes the intensity of aversion to advantageous inequality, i.e. the disutility of a subject on being ahead of her rival. For simplicity, we assume that the inequality parameters are common for both contestants.

Trautmann (2009) extends the model to games with a stochastic outcome and show that it leads to different predictions conditional on subjects' preferences for process-based or outcome-based fairness. For the case of process-based fairness inequalities are calculated in terms of expected payoffs, i.e. the expected profit π_i^P for the Tullock lottery contest is

$$U_i^P = E_i + \frac{a_i e_i}{a_i e_i + a_j e_j} V_i - e_i - \alpha \max\{E(\pi_j) - E(\pi_i), 0\} - \beta \max\{E(\pi_i) - E(\pi_j), 0\}$$

In the outcome-based fairness expected profit function π_i^O, inequalities are based on realised payoffs weighted by their probabilities of realisation, i.e.

$$U_i^O = E_i + \frac{a_i e_i}{a_i e_i + a_j e_j} V_i - e_i - \alpha \, E\big[\max\{\pi_j - \pi_i, 0\}\big] - \beta \, E\big[\max\{\pi_i - \pi_j, 0\}\big]$$

Fonseca (2009) analyses subjects' choices in both the symmetric contest and a contest with asymmetric abilities using the process-based model and finds that it fails to predict high bids.[1] Herrmann and Orzen (2009) and, more recently, Rockenbach and Waligora (2016) compared choices in the symmetric game with the predictions of the outcome-based model. Both studies also reject the hypothesis that F&S preferences explain overbidding in the symmetric game.

When contestants are equal in all characteristics, the level of predicted rent-seeking is above the standard Nash Equilibrium predictions with both approaches, for any $\alpha > \beta$. However, the predicted effort by contestants is similar with the two approaches only if $\alpha = \beta - 2\beta^2$, and

[1] It is worth mentioning that, contrary to what is stated by Fonseca (2009), the resulting equilibrium depends on the values of α and β and it is not always symmetric.

differs otherwise. If players are equal in all characteristics, $e^{*P} \geq e^{*O}$ if $\alpha \geq \beta - 2\beta^2$ and $e^{*P} < e^{*O}$ otherwise.

With the introduction of inequalities, the process-based and the outcome-based models can lead to different equilibrium predictions due to differences in the treatment of the model parameters α and β. For example, the former disregards differences in endowment while the latter does not. Moreover, the best-response functions of the process-based model include only one of the two inequality preferences parameters for each contestant,[2] while both are present in the outcome-based. Such differences in the models lead to predictions that are both quantitatively and qualitatively different, i.e., different not only in magnitude but also in the direction of differences between players' expenditures.

In all cases the symmetric equilibrium is an exception, while asymmetric equilibria depend on the values of inequality aversion. Further, such models of social preferences allow for multiple equilibria. Many patterns of behaviour can thus be rationalised as equilibrium behaviour under different values of the inequity aversion parameters. As a result, we are unable to generate clear predictions without additional assumptions on the strengths of agents' social concerns.

We graphically show below that under the outcome-based model, even with moderate inequality-aversion parameters, multiple equilibria may arise in the case of asymmetric ability. Further, in such equilibria, either the disadvantaged or the advantaged players exert more effort. Extending the analysis to other types of inequality, endowment inequality widens the gap between contestants' efforts, as less wealthy players will tend to spend less than their opponents. In the case of unequal prize valuations, inequality concerns can lead to asymmetries between players' efforts in both directions depending on the values of α and β.

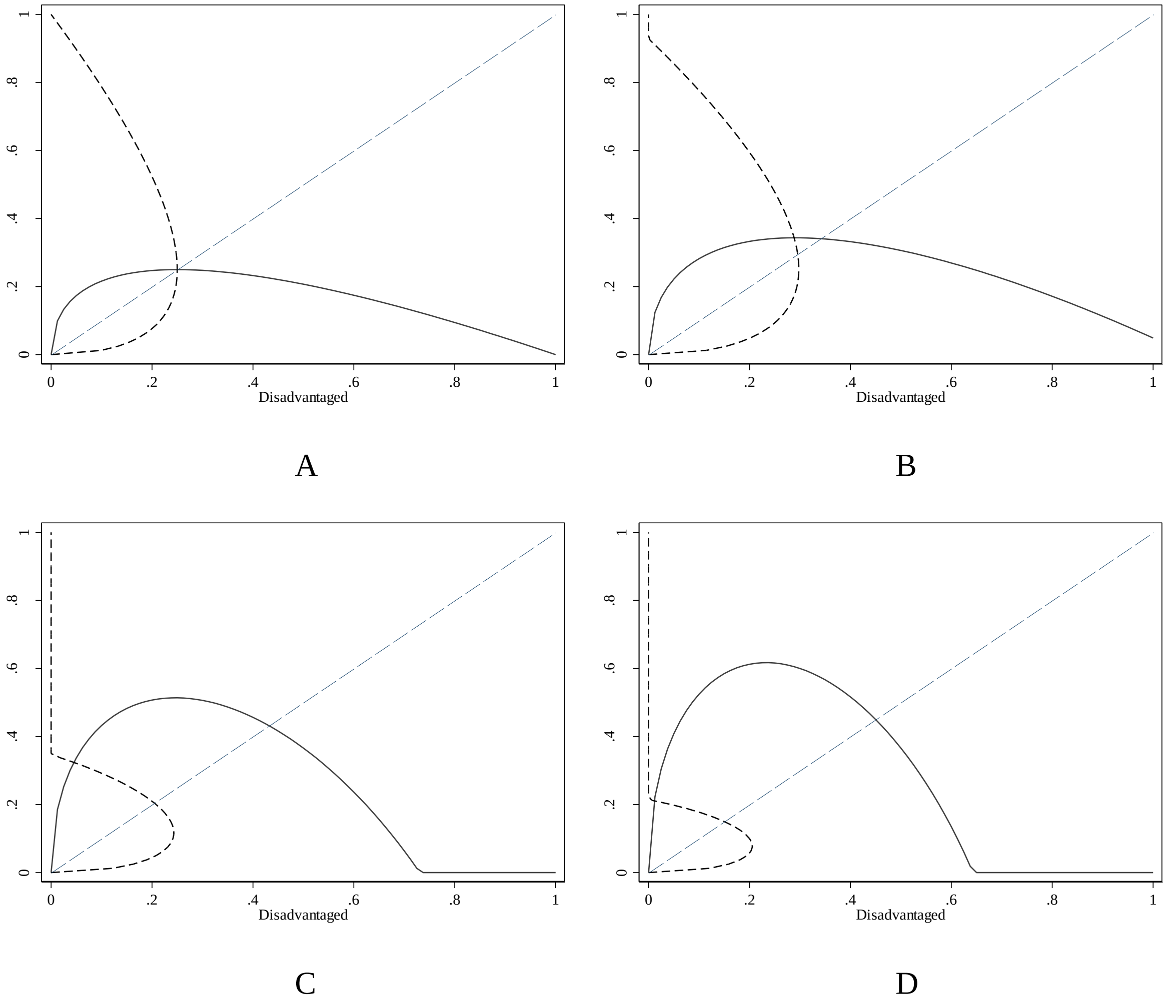
We plot four examples of the best-response functions for each of the three inequalities implemented in the paper. With inequality in ability and endowment we normalize the prize value to 1, while for the inequality in prize valuation we normalize the average valuation to 1. Panel A shows the standard best response functions ($\alpha = \beta = 0$); in Panel B we consider a negative β to account for the joy of winning (e.g. Parco et al., 2005; Sheremeta, 2010) ($\alpha = 0.5, \beta = -0.25$); in panels C and D we consider two cases of moderate inequality aversion with $\alpha > \beta$ (C $\alpha = 1, \beta = 0.25$; D $\alpha = 1, \beta = 0.5$).

[2] β in the best-response function of the contestant with the higher expected payoff and α in the best-response function of the contestant with the lower expected payoff.

B1. Resources (ASYM-E)

Without inequality concerns, the best response functions are similar to the symmetric treatment. F&S predictions under inequality aversion negatively affect the bids by disadvantaged players.

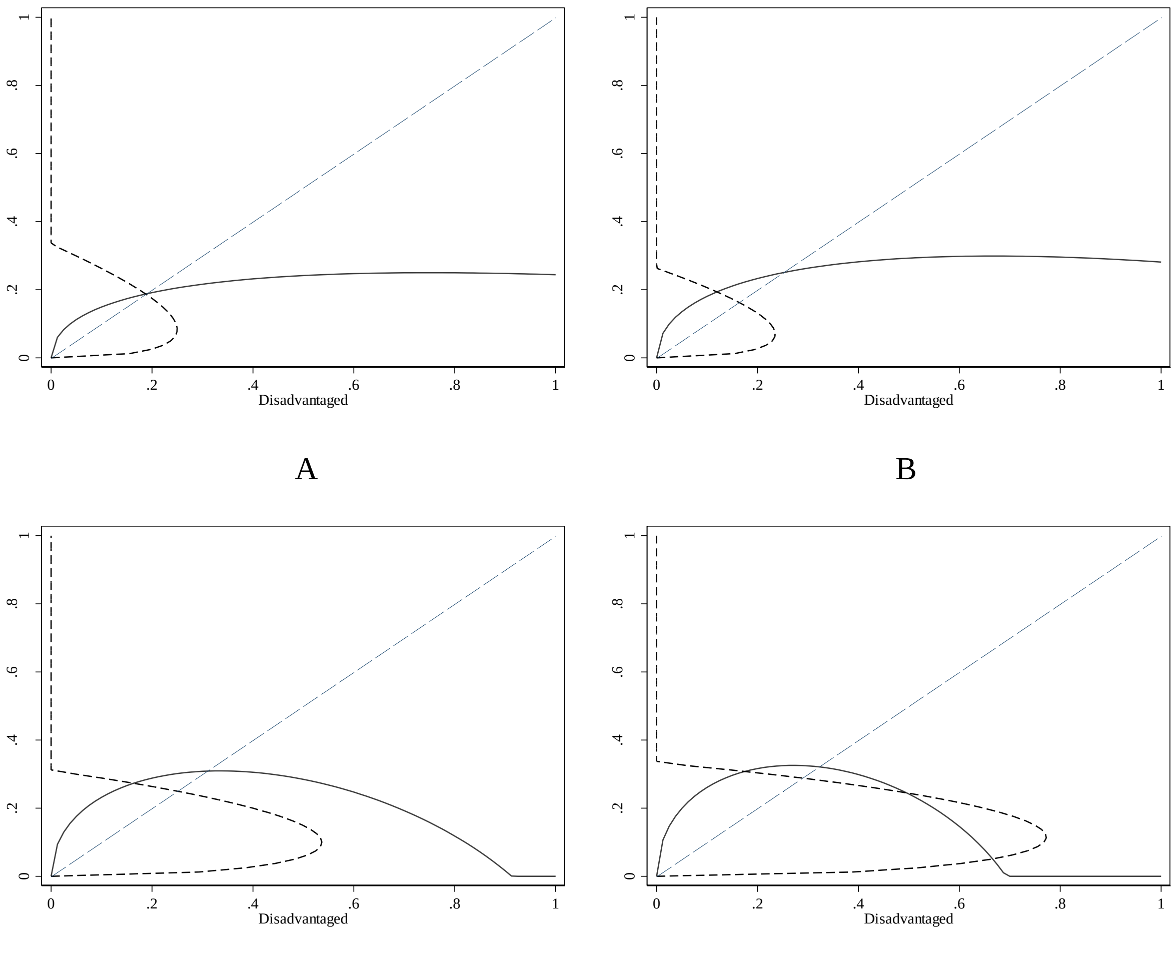
Figure B1. Reaction functions by player type under inequality in endowments ($\boldsymbol{Ei - Ej = 0.5}$)



B2. Ability (ASYM-A)

With a >1, the predicted equilibrium tends to be asymmetric for a wide range of inequality parameters. In panels B-C-D we always observe an equilibrium in which the advantaged player tends to bid higher than the disadvantaged. However, by increasing the disadvantageous inequality parameter we have multiple equilibria, some of which have the disadvantaged player expending more resources than the advantaged.

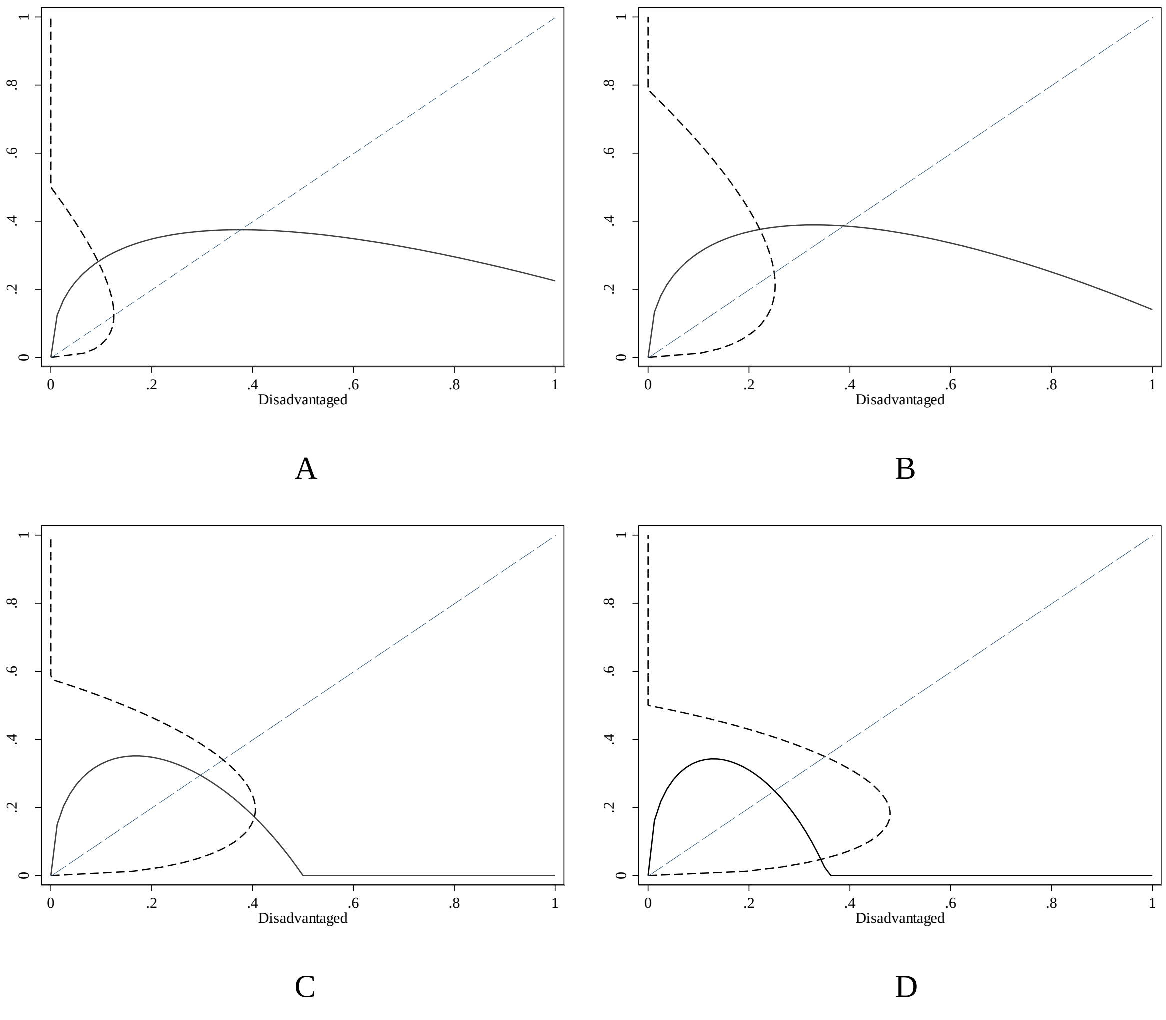
Figure B2. Reaction functions by player type under inequality in abilities (*a*=3)



B3. Prize valuation (ASYM-V)

The inequality parameters affect the asymmetric equilibrium the resulting equilibrium change direction on the basis of sign of β. With a negative β (panel B) the bid of the advantaged player is higher than the disadvantaged player. With a positive β (panel D) the asymmetry reverses, with the disadvantaged player expending more resources.

Figure B3. Reaction functions by player type under inequality in prize valuations ($\boldsymbol{\theta = 3}$)



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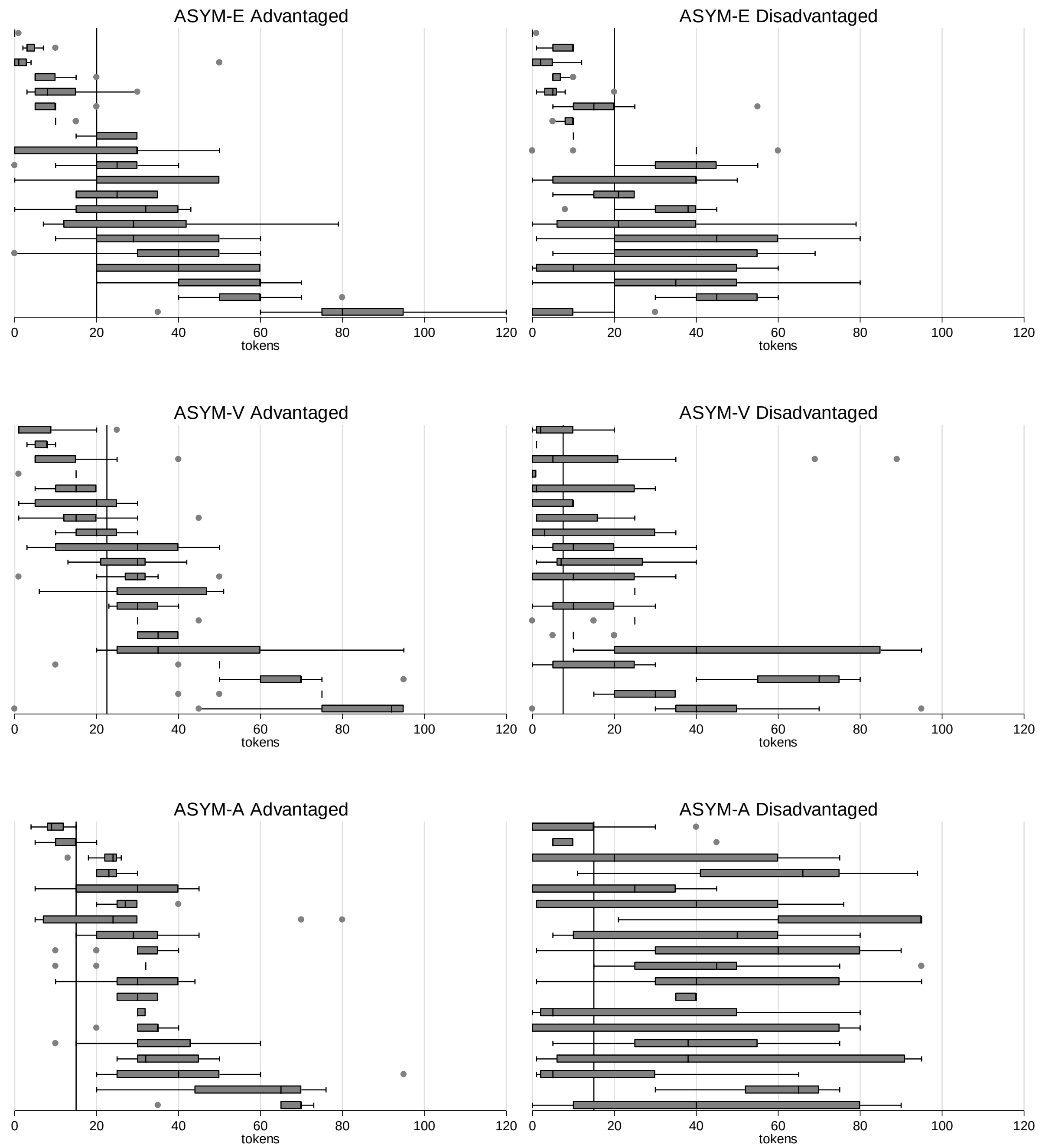
Appendix C – Boxplot of individual bids

Figure C1 shows the boxplots of individual choices in the last 15 rounds, grouped by treatment and player type. Competing pairs are ordered by increasing mean effort choices of the advantaged player in the pairs. For each treatment, the boxplot on the left shows the distribution of efforts of the advantaged player, and the corresponding line in the boxplot on the right shows the distribution of efforts of the disadvantaged player in that same pair.

Figure C1. Boxplot of individual bids in the last 15 rounds in the asymmetric treatments. Subjects are sorted in increasing order by mean bid of the advantaged player in the pairs. Vertical black lines indicate Nash Equilibria.



The behaviour of advantaged players in ASYM-V and ASYM-E is similar, with median choices of the majority of subjects being at or above the equilibrium and effort choices being similarly dispersed. The majority of the median efforts of disadvantaged players are below or near their respective equilibrium predictions. Also, within-subject variation in behaviour is similar across the two treatments and types, and overall effort appears to be correlated with that of their advantaged opponents.

In ASYM-A, the efforts of advantaged players are stable at the individual level, and for the majority of contestants the median is at or around 30 tokens. Median efforts of the majority of disadvantaged players are well above the equilibrium and choices are more dispersed. Advantaged players do not respond/adapt to the efforts of their opponents, as is the case in the presence of other asymmetries.