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Group Size and Matching Protocol in Contests

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Abstract

We investigate the effects of group size and matching protocol in Tullock contest experiments. In a 2x2 factorial design we implement partner and random stranger matching protocols in contests between two and between three players. Group size does not affect overall absolute bid levels, but the rate of overbidding is lower in two-player groups across matching protocols. Matching protocol does not affect bidding behavior for three-player groups, but a partner matching reduces both the level and dispersion of bids in two-player groups. These results show the joint effect of group size and matching protocol, and suggest that identifiability in repeated play facilitates tacit collusion.

JEL Classification: B41; C72; C91

Keywords: Contest; Experiment; Matching protocol; Group size; Experimental methodology

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1. Introduction

Contests are situations in which people expend costly and irreversible resources in order to win valuable rewards or prizes. Tullock (1980) coined a type of contest in which the contestants make sunk bids, and the probability of winning is the ratio of one's bid to the total bids made by all the contestants. Various real life situations such as patent races, rent-seeking games, research funding applications, lotteries, promotional tournaments, sports, litigations, warfare and terrorism can be modeled as such a contest.

In many of these cases, players take part in the contest repeatedly, and there are important aspects – usually out of the control of the players – that affect their behavior. Two such prominent aspects are: how those players are matched in the repetitions (known as the 'matching protocol'), and the number of competing players (often called the 'group size'). In some contests, e.g., protracted war with repeated battles, the same set of players compete for prizes repeatedly. In others, such as in lotteries, they largely compete with different players each time. Furthermore, in some contests as in sports, only a handful of players compete for the prize at a time; while in some other contests, such as in lotteries, many players compete for the same prize.

It is well known that repeated interactions can have important reputation as well as learning effects and can thus influence behavior (Berg et al., 1995). In repeated contests among the same set of players, the involved parties may draw inferences about others' types in terms of willingness to tacitly collude, spitefulness etc., and signal their own type. Such behavior can be particularly strong in small groups, in which it is relatively easy to observe and process the actions of others. As a result, matching protocol and group size can have significant joint effects on behavior in contests. Studying just one or the other could, thus, may lead to a partial and incomplete understanding of human behavior.

Standard theory provides specific predictions on the effects of group size, but is silent on the effects of matching protocol. Field data on contests are hard to obtain, and when available, are often noisy. But laboratory or field experiments allow control and clear identification of causal channels, providing a reliable way to analyze these issues. However, as we elaborate in the next section, experimental studies of contests investigating the issue of matching protocol are rare, and this is the only analysis that considers interaction of matching protocol with group size.

In the current study we present a laboratory experiment designed to investigate the effects of matching protocol, group size, and their interplay on behavior in finitely repeated Tullock contests. These effects are important for a contest designer in the field, and an experimental researcher in the laboratory. Our study hence provides a two-fold contribution. First, there are specific contests such as sporting events, patent races, or funding application competitions, in which the contest designer has high influence to set matching protocols in the field. The results from this study will allow a better understanding of the underpinning mechanisms of behavior in such contests and help the designer on optimally design such contests according to her objectives. Second, experimental contest researchers often implement a particular matching protocol without an existing information about whether such protocol has any influence in the subject behavior. Hence, at a methodological level, our study will provide significant direction to the designer of future contest experiments that rely on a repeated setting.

A repeated contest among the same players is operationalized in the laboratory using a partner matching protocol, in which subjects in the same subset of a cohort interact with each other throughout an experimental session. This is in contrast to a stranger matching in which groups of subjects are re-matched in every period of a session.[1] It is observed in various experiments that a

[1] There are mainly two types of stranger matching employed in the experimental literature. In a 'perfect stranger' matching a subject is matched with another subject only once in a whole session. In a 'random stranger' matching the subjects are randomly re-matched in each period and two subjects may be matched more than once (Botelho et al.,

partner matching frequently results in reputational effects and collusion.[2] This idea is often used to understand behavior in the market, but never in the contest. Since contest experiments are known to record overbidding of resources relative to the equilibrium (Dechenaux et al., 2015), a partner matching may allow players in contests to tacitly collude and reduce wasteful overbidding.

It is also shown in the experimental literature that collusion is easier among a limited number of players (Huck et al., 2004). One would thus expect the effects of matching protocol to interact with the number of players in a contest. In this study we begin with group size 3, the most commonly used group size in the contest experiments (Dechenaux et al., 2015) and in market experiments on cartels (Huck et al., 2004). We then employ group size 2, the size that has been found to be the most likely to elicit tacit collusion in various settings.

Consistent with the existing studies, we find significant overbidding in all the treatments. There is no difference in bid levels, in bid dispersion, or in the overbidding rates (defined as the bid over the Nash equilibrium level scaled with the Nash bid) between the two matching protocols for group size 3. However, all of these statistics are often significantly lower with partner matching than in stranger matching for group size 2. These imply that two-player groups are able to reduce both overbidding and overbidding rate in repeated interaction under partner matching protocol.

These results are of importance for several reasons. First, they allow one to identify the effects matching protocol and group size have on a contest, and thus provide a better understanding of behavior for contest designers. For example, a contest designer is likely to elicit higher effort in a two-player contest with a stranger matching than with a partner matching.

2009). In this study, we focus on the random stranger protocol as this is "*by far the most popular operational counterpart of a one-shot environment in experiments*" (Botelho et al., 2009, p. 254), including contests (Sheremeta, 2013). We use the terms 'stranger' and 'random stranger' interchangeably in this study.

[2] For example, Andreoni and Miller (1993) in Prisoners' dilemma and Croson (1996) and Fehr and Gächter (2000) in public goods games find higher level of cooperation among subjects when a partner matching is employed, and especially when players can use disciplining mechanisms viz. punishment (Fehr and Gächter, 2000). This is argued to be due to reputation and reciprocity effects, which a stranger matching eliminates (Andreoni and Croson, 2008). See also Chowdhury and Crede (2020) and the references therein for similar results in market experiments.

Second, the results suggest that the matching protocol does not significantly alter behavior in ‘large’ groups. Thus, in terms of logistics in a laboratory experiment, a partner matching might be preferable. This is because in the partner treatments, each group forms an independent observation since there is no spillover across groups even within a session. However, in the stranger treatments subjects participate in different groups in each period and each session represents an independent observation in the stranger treatments. Hence, for the same research budget for an experiment, a stranger matching protocol provides a smaller number of independent observations. Furthermore, the possibility of contamination of the whole session by technical glitches, or due to an extreme behavior by even one subject poses a larger risk under stranger matching than in partner matching where data contamination is limited to one group.

Finally, as we discuss in the next section, there is insufficinet consensus in the literature on the effect of group size on behavior in contests. This study permits this area of literature to have a clearer understanding by considering the additional impact of matching protocol.

2. Literature Review

There exists a undersized body of work that investigates the effects of matching protocol in a variety of contests. Mentioning the issue for the first time, Durham et al. (1998) observe traces of collusion, in the sense of lower bidding, in a ‘production and conflict’ game when a partner matching is employed. However, the effects of matching protocol are not tested here. Lugovskyy et al. (2010) find that bids in an all-pay auction are lower with a partner matching than with a stranger matching, but the difference is not statistically significant. Lacomba et al. (2014) observe lower post-conflict bids under partner matching in a production-conflict framework, but the significance of the result is not tested. Chowdhury et al. (2013) investigate the Colonel Blotto game, a multi-battle contest, and observe serial correlation in bids across periods in a given battlefield. They find that such correlation is significantly reduced under partner matching. Vandegrift and Yavas (2010) study a tournament with the option to sabotage. The levels of both bids and sabotage decrease when a partner matching is employed. Fallucchi and Renner (2016) consider investigating matching protocol in an individual contest. They explore the interaction between the matching protocols and the level of information feedback on bidding behavior. Finally, investigating the level of bids in his meta-analysis, Sheremeta (2013) uses an indicator variable for matching protocol; the coefficient is not statistically significant.

Hence, existing studies analyzing the effects of matching protocol are either concentrated on mechanisms other than standard contests, or on research questions in which various issues such as production, or sabotage, or information are conjoined along with bidding behavior. Oftentimes the descriptive statistics show mixed results, and/or the statistical significance of these results remain untested. Almost all the experimental studies of repeated Tullock contests use *either* a partner *or* a random stranger matching protocol without justifying the implementation. In the meta-analysis, for example, Sheremeta (2013) considers 30 well-known experimental studies spanning the years 1989 to 2013. Of these, 10 studies use partner matching, 17 use random stranger matching, and the remaining 3 are one-shot experiments. There exists no study testing the effects of matching protocol in this environment and thus "*there is no agreement on how matching protocol influences individual behavior*" (Sheremeta, 2013, p. 508).

Turning to the effects of group size, existing work on collusion among firms in a market suggests an increase in collusion (i.e., reduced competition) with a decrease in group size. Selten (1973) shows theoretically that collusion becomes more difficult as the number of firms in the market increases. Dolbear et al. (1968) show that successful collusion becomes more likely as the number of firms in the experimental market is decreased linearly from four to two. Dufwenberg and Gneezy (2000) find collusion between two price-setting firms but also find that collusion breaks down and competition prevails with more firms. In a Cournot setting, Huck et al. (2004) reaffirm that collusion works well in markets with two firms but its effectiveness declines in larger markets. Fonseca and Normann (2012) find such a relationship also in a Bertrand setting.

Theory in symmetric Tullock contests predicts a decrease in competition (in terms of individual bids) with an increase in group size. Experimental evidence on group size effects in contests, however, is mixed. In a setting that includes cost heterogeneity and contest entry fees, Anderson and Stafford (2003) study behavior in homogeneous groups with 2, 3, 4, 5 or 10 players and find support for the theoretical prediction. Sheremeta (2011) indirectly observes an effect of group size on bids. He observes lower bids in a grand contest with four players than in two sub-contests with two players each. Morgan et al. (2012) find support for a negative relation between bids and group size in contests with entry and endogenous group size. However, Lim et al. (2014) is the only study specifically designed to investigate bidding in Tullock contests with exogenously varying group sizes. They find, under only a stranger matching protocol (hence, without the possibility of a tacit collusion), that group size (2, 4, and 9) does not significantly affect individual bids and explain the phenomenon with bounded rationality models.

Thus, the effects of group size on bids in Tullock contests mostly have not been investigated in the literature. To our knowledge, the current one is the first study to investigate the effects of group size, matching protocol *and* their interaction.

3. Theoretical Background

We consider a rent-seeking contest with N identical risk-neutral players, each with budget B. Player i, for $i = 1, 2, 3, \dots N$, chooses his bid $b_i \in [0, B]$ to win a single prize of common value $V > 0$. Irrespective of the outcome of the contest, players forgo their bids. The probability that player i wins the prize, $p_i(b_i, \boldsymbol{b_{-i}})$, where $\boldsymbol{b_{-i}}$ is the vector of bids of all players except i, is represented by a lottery contest success function (Tullock, 1980):

$$p_i(b_i, \boldsymbol{b_{-i}}) = \begin{cases} b_i / \sum_j b_j & \text{if } \sum_j b_j \neq 0 \\ 1/N & \text{otherwise} \end{cases} \quad (1)$$

Given (1), the expected payoff for player i is: $E(\pi_i) = p_i V + (B - b_i)$

Following standard procedures, the Nash equilibrium bid is:[3]

$$b^* = (N-1)V/N^2 \quad (2)$$

And the expected payoff at the Nash Equilibrium is: $\pi^* = B + V/N^2$

The unique sub-game perfect Nash equilibrium remains the same in a finitely repeated contest with either the same or different rivals in each repetition. This theoretical model provides us with two precise predictions. First, the equilibrium bid decreases with an increase in group size. Second, the equilibrium bid is unaffected by the matching protocol.

4. Experimental Design and Procedure

In all sessions, subjects played the contest game described above repeatedly for 25 periods. In each period a group of N players competed for a prize of 180 tokens, i.e., $V = 180$. Each player was given a budget of $B = 180$ tokens in each period that they could use to bid for the prize. Players could enter bids up to one decimal place. At the end of each period, subjects received feedback on the individual bids in their group and whether or not they won the prize. While they competed in each of the 25 periods, subjects were paid their average earnings in five of these periods chosen

[3] The existence and uniqueness of the equilibrium is from Szidarovszky and Okuguchi (1997) and Chowdhury and Sheremeta (2011). We ensure that the budget is larger than the equilibrium bid i.e., $B > (N-1)V/N^2$.

randomly (this was done to avoid possible income effects). All subjects were paid for the same five periods. All design elements were made public knowledge to all subjects in every session.

We employed a 2 × 2 factorial design varying two dimensions – matching protocol (partner vs. random stranger) and group size (2 vs. 3), resulting in four treatments. In each session of the *Partner* treatment the *N* subjects were matched as one set of contestants, and the matching did not change during the session. The matching changed randomly in every period of the *Random Stranger* treatment. These were made clear in the instructions (included in the Appendix). Note that these are very standard procedures followed in the contest literature (Dechenaux et al., 2015).

It could have been possible for us to implement even bigger group sizes (4, 5, 6, 7, …) to observe the group size effect. However, our focus has been the interaction between group size and matching protocol. For stranger matching, it is not possible for the subjects to signal their 'type' to the rival, but it is possible to do so in the partner matching. A subject can 'punish' the partner's high bid with a future high bid, and 'reward' a low bid with a future low bid. Given the experimental setting, this type of targeted signaling can be done only for the 2-player case, since doing so in the 3 (or more) player case will affect all the other group members. Hence, tacit collusion, and resulting lower bids can occur for the 2 player case but not for the 3 (or more) player case. Similar phenomenon is observed in public good game, and in the market games. The existing experimental Industrial Organization literature (Dufwenberg and Gneezy, 2000; Huck, Normann and Oechssler, 2004) shows that tacit collusion breaks down for more than 2 players and does not arise even after adding more players. If this conjecture works for 3 players in contest, it should work also for more than 3 players, since targeted signaling is not possible for such cases either. Hence, we consider only 2 and 3 player groups.

Equation (2) gives the equilibrium bid in each of the 25 periods. The equilibrium bid is 40 tokens for group size 3 and 45 tokens for group size 2. Table 1 summarizes the design and presents the number of subjects in each treatment. We denote the treatment with partner matching and group size 3 as **Partner 3** and so on.

Table 1. Summary of treatments (number of subjects)

	Group size	
Matching protocol	$N = 3$	$N = 2$
Partner	Partner 3 (54)	Partner 2 (36)
Stranger	Stranger 3 (54)	Stranger 2 (36)
Equilibrium bid	40	45

We chose group size 3 to ensure that a 'baseline' resembles the standard contest experimental designs. Group size 2 provides one with the best-shot at signals over repeated interaction and possible tacit collusion in a non-cooperative game when a partner matching is implemented (Fonseca and Normann, 2012). The number of subjects is higher in the group size 3 treatments to keep the number of competing groups, 18, the same across treatments.[4] The prize value was such that the equilibrium bid is a round number in both group sizes and thus provides a straightforward theoretical comparison of equilibrium bids across the two. It could have also been possible to simultaneously change the group size as well as the prize value to keep the Nash equilibrium bid the same, and investigate any difference in observed bids. We instead chose to follow the standard procedure and changed only one element at a time. Finally, based on previous findings (Huck et al., 2004), we anticipate possible collusion will break down at group size 3 and

[4] Note that under stranger protocol given the same cohort size (18) per session, the probability that that a subject will be matched with another particular subject in the next period is 0.654% for 2-player case and 1.961% for 3-player case. Although the probabilities are different, they are extremely small and negligible. Furthermore, any interaction in the experiment was always anonymous; hence subjects had no way to find out whether someone actually is matched with them in a particular period. Hence, we implement this design. It will be of future research interest to investigate subject behavior, if the differences are significant enough. We thank an anonymous referee to point this out.

that group sizes larger than 3 are unlikely to result in reverting to collusion. Hence, we do not run treatments with groups bigger than 3.

The computerized experiment was run at a laboratory of the Centre for Behavioural and Experimental Social Science at the University of East Anglia using z-tree (Fischbacher, 2007). The subjects were students from the University and the 18 subjects in each of the 10 sessions were recruited through ORSEE (Greiner, 2015). Each session had two parts. First, we ran the Eckel and Grossman (2008) version of the risk elicitation task introduced by Binswanger (1981), but the outcome of the task was not revealed until the end of the experiment. The second part consisted of the 25 periods of the contest. Subjects had to answer a quiz that tested their understanding of the game and payoff calculations before the second part began. At the end of each session, we collected demographic information through a survey. No subject had participated in any contest experiment before, but they might have participated in other economics experiments. Each session lasted for around 50 minutes. At the end of each session, token earnings were converted to GBP at the rate of 1 token to 3 pence. Subjects, on average, earned £7.82.

5. Hypotheses

The strategy space for players in all the treatments is the same: [0, 180]. We can thus easily compare the absolute levels of bids across treatments in a straightforward manner. A robust finding in the experimental literature on contests is that subjects consistently overbid, i.e., bid more than the theoretically predicted Nash equilibrium bid level (Dechenaux et al., 2015). We do not expect a different result and state it formally as our first hypothesis.

Hypothesis 1. There exists overbidding across group sizes and across matching protocols.

For finitely repeated contests, theory predicts the same level of bids in equilibrium when the group size is the same – irrespective of the matching protocol. This is hypothesis 2.

Hypothesis 2. There exists no difference in individual bid levels across matching protocols for a fixed group size.

Although we expect overbidding across treatments, theory clearly predicts a higher equilibrium bid for a lower group size. This is reflected in the next hypothesis.

Hypothesis 3. Individual bids are higher in the treatments with group size 2 than in the treatments with group size 3 under both matching protocols.

6. Results

6.1 Bidding behavior

Table 2 presents summary statistics of individual bids in each treatment, averaged over 25 periods.

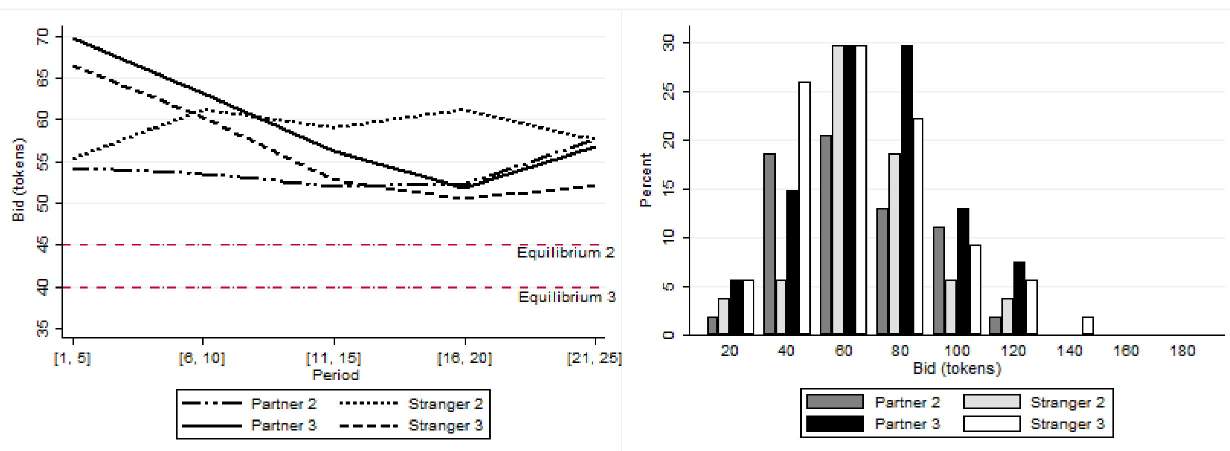
Table 2. Means (standard deviations) of individual bids

	Group size	
Matching protocol	N = 3	N = 2
Partner	59.581	53.926
	(25.404)	(23.335)
Stranger	56.467	58.872
	(27.137)	(21.983)
Obs. (per cell)	54	36
Equilibrium bid	40	45

It can be observed from Table 2 that average bids are above the equilibrium predictions in all the treatments. Also, both the level and dispersion of bids for group size 3 are higher than for group size 2. Finally, average bids in the stranger treatment are higher than those in the partner treatment for group size 2 only.

Figure 1 plots the average bids over periods (left panel) and over the bid range (right panel). The left panel confirms that overbidding occurs throughout the periods in all treatments. The right panel also shows that in the treatments with group size 3, bids are distributed over the whole bid range while bids are concentrated mostly below 100 in the treatments with group size 2. Furthermore, as observed in Table 2, dispersion (termed as 'overspreading') in bids is higher in the Partner treatments for both group sizes. We first focus on the level of bids, and discuss the dispersion of bids in Section 6.3.

Figure 1. Average bids over periods and over the bid-range



These observations are in line with the existing results on overbidding and overspreading in contests (Chowdhury et al., 2014; Lim et al., 2014), and show that they are robust to the choice of matching protocol and group size. We now test the statistical significance of these observations. We estimate four individual-level panel random effects regressions, one for each pair of treatments, on a constant and a dummy (stranger treatment when we consider group size, and group size 2 when we consider matching protocol).[5] The dependent variable is the deviation of an individual's

[5] In the stranger treatments, each session represents an independent observation. Thus, the number of independent observations is not large enough to run the usual aggregate parametric and nonparametric tests. Regressions allow us to control for the lack of independence within a session by using multi-level clustering of standard errors. This is a very standard procedure employed in the literature (see the survey by (Dechenaux et al., 2015) or the meta-analysis by Sheremeta (2013) for further details).

bid from the equilibrium bid ($= b_i - b^*$) in a period. Since we are only interested in means relative to the equilibrium, we do not control for other individual characteristics at this stage. To account for the lack of independence within sessions in the stranger treatments, we calculate standard errors clustered at the session level and at the individual level. A significant positive coefficient of the constant term would constitute evidence of significant overbidding. The results are presented in Table 3. Other specifications such as using the whole data and including matching protocol dummy, group size dummy, and their interaction provide qualitatively similar result.

Table 3. Overbidding: panel random effects regressions

		Group size		Matching protocol	
Dep var: $(b_i - b^*)$		N=3	N=2	Partner	Stranger
Stranger matching Indicator		-3.114 (5.153)	4.946^{***} (0.989)	-	-
Group size 2 Indicator		-	-	-10.655^{**} (4.964)	-2.595 (1.985)
Constant		19.581^{***} (4.782)	8.926^{***} (0.935)	19.581^{***} (4.881)	16.467^{***} (1.960)
R^2		0.0036	0.0121	0.0440	0.0026
Observations		2700	1800	2250	2250
No. of clusters	Sessions	6	4	5	5
	Individuals	108	72	90	90

Robust s.e. clustered at two levels, session and individual, are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The coefficient estimates of the constant are positive and significant at the 1% level in each of the regressions, implying overbidding in each of the treatments separately. This is summarized in Result 1 that provides support for Hypothesis 1.

Result 1. Observed bids are significantly higher than the equilibrium bids for both group sizes and for both matching protocols.

The first two regressions specify that the bids are significantly above equilibrium in the partner treatment across group sizes. The positive coefficients of the stranger dummies (which is significant only for group size 2) further show that the overbidding in the stranger treatment is at least as high as the overbidding in the partner treatment for group size 3 and strictly higher for group size 2. The negative and (significant for partner) coefficients of the group size 2 indicator in the next two regressions further confirm that overbidding is lower for a smaller group than a bigger one in both matching protocols. Result 2 summarizes these findings.

Result 2. Overbidding is more prominent for group size 3 under the partner matching protocol, but there is no difference between group sizes under stranger matching. Furthermore, when a stranger matching is employed, overbidding increases only for group size 2.

6.2 Joint effects of matching protocol and group size

We now analyze the effects of matching protocol and group size on bidding behavior, while controlling for other factors. We estimate individual-level random effects panel regressions of an individual's bid in a period on a dummy for either matching protocol or group size and control for observed past outcomes: one-period lagged value of own bid, an indicator for whether or not the individual won the contest in the previous period and the total bids of the others in the group in the previous period. We also control for an individual's demographic characteristics. In particular, we include a female gender dummy, age (in years), and an indicator for a preference for risky behavior. The risk elicitation task had six options (1–6) in increasing order of risk. The risky behavior indicator takes the value 1 for subjects who chose option 4–6 and 0 otherwise (the results are robust to alternative definitions of the indicator). In addition, we include a time trend (Period). As in the previous regression, we calculate standard errors clustered at the session and at the individual levels. The regression results are reported in Table 4.

Table 4. Bidding behavior: random effects panel regressions

Dep var: Individual bid		Group size		Matching protocol	
		N=3 (Ind info)	N=2	Partner	Stranger
Stranger matching indicator		-1.066	0.748***	-	-
		(3.145)	(0.275)		
Group Size 2 indicator		-	-	3.221	2.759**
				(4.425)	(1.409)
Lag of own bid		0.383***	0.600***	0.374***	0.548***
		(0.061)	(0.054)	(0.076)	(0.039)
Previous period win indicator		4.587***	-3.144***	0.525	-0.580
		(1.323)	(0.534)	(2.750)	(1.579)
Lag of others' bid		0.046**	0.163***	0.100***	0.035
		(0.023)	(0.059)	(0.038)	(0.025)
Period		-0.376***	0.049**	-0.117	-0.159
		(0.054)	(0.025)	(0.147)	(0.128)
Risky behavior indicator		-0.389	-0.954	-6.441	2.604
		(4.973)	(3.079)	(4.850)	(3.732)
Female indicator		2.236	1.067**	-3.301	4.583*
		(3.629)	(0.532)	(2.106)	(2.579)
Age		-0.201***	-0.053	0.002	-0.186***
		(0.067)	(0.292)	(0.287)	(0.032)
Constant		37.94***	15.23**	31.82**	24.57***
		(7.722)	(6.793)	(14.96)	(2.174)
R^2		0.1828	0.4250	0.1826	0.3235
Observations		2592	1728	2160	2160
No. of clusters	Sessions	6	4	5	5
	Individuals	108	72	90	90

Robust s.e. clustered at two levels, session and individual, are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

We first consider the effects of matching protocol. The coefficient of the stranger matching indicator is positive for both the group sizes and significant at 1% level for group size 2 but is not significant for group size 3. This indicates that the matching protocol does not have an effect on bidding behavior for group size 3. But for group size 2, which provides the best-shot for possible tacit collusion, a partner matching indeed leads to lower bids. This is a new and important finding in the contest literature, and is summarized in Result 3.[6]

Result 3. Bids are not significantly different between matching protocols in group size 3. However, bids are significantly lower under partner matching than under stranger matching in group size 2.

Result 3 provides mixed support for Hypothesis 2. When the group size is 3, the hypothesis cannot be rejected. However, in line with observations from experimental industrial organization, Result 3 suggests that a partner matching with only two players allows them to signal each other's willingness to collude. This could invoke tacit collusion and, as a result, significantly lower bids, thus rejecting the hypothesis.

Turning to the effects of group size we focus on the last two regressions. The coefficient of the group size 2 indicator is negative but not statistically significant for both matching protocols. The effects of the controls are, again, standard. The result is formally stated below. This result allows us to reject Hypothesis 3.

Result 4. Bids are not significantly different across group sizes under partner matching, and are marginally lower in groups of size 3 under stranger matching.

This result complements the result of Lim et al. (2014) who find no effect of group size for group sizes 2, 4 and 9, albeit employing only a stranger matching protocol. Result 4 extends this finding to partner matching as well.

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[6] The controls in general show expected signs and significance levels. The results such as auto-correlated bids and higher bids by females are already noted in the literature (Price and Sheremeta, 2015). Some other results such as strategic interaction variables e.g., lag of rival's bid, or own win is significant only for group size 2 reflects reputation effects. There is also an end period effect after 20 periods for group size 2 (as can also be observed in Figure 1) possibly due to break-down of tacit collusion under partner matching – making the effect of time trend weakly positive whereas for all the other cases the effect is negative. We observe a positive and significant coefficient for the variable 'Lag of others' bid' only for the partner treatment, which indicates the signal to punish high bid with a future high bid, and reward low bid with a future low bid.

Note, however, that the equilibrium bid is higher in the smaller groups. Hence, the same bid implies a lower rate of overbidding (relative to the equilibrium) in smaller groups. Thus a comparison of the absolute bids across treatments (as in Result 4, and in Lim et al., 2014) presents a partial picture of bidding behavior. To compare overbidding behavior between the two group sizes, we define individual i's overbidding rate (Sheremeta, 2013) as: $r_i = (b_i - b^*)/b^*$. Thus, $r_i = 0$ if and only if the bid equals the equilibrium prediction. A negative (positive) value indicates underbidding (overbidding) relative to equilibrium.

Table 5 provides descriptive statistics for the overbidding rate that is comparable to the information about bid levels in Table 2. It can be observed that overbidding rates (and its dispersions) are higher for group size 3 across matching protocols. Also, average overbidding rates in the partner treatment are lower than those in the stranger treatment in both group sizes.

Table 5. Means (standard deviations) of overbidding rates

	Group size	
Matching protocol	N = 3	N = 2
Partner	0.489	0.198
	(0.635)	(0.519)
Stranger	0.412	0.308
	(0.578)	(0.489)
Obs. (per cell)	54	36
Equilibrium bid	40	45

We estimate random effects panel regressions as in Table 4 but now consider the overbidding rate as the dependent variable. The independent variables are the same as those in the regressions reported in Table 4. The regression results are reported in Table 6 below.

Table 6. Overbidding rates: random effects panel regressions

Dep Var: $(b_i - b^*)/b^*$	Group size		Matching protocol	
	N=3	N=2	Partner	Stranger
Stranger matching Indicator	-0.027 (0.079)	0.017*** (0.006)		
Group size 2 Indicator			-0.084 (0.109)	-0.095*** (0.035)
Lag of own bid	0.009*** (0.002)	0.013*** (0.001)	0.009*** (0.002)	0.013*** (0.001)
Previous period win indicator	0.115*** (0.033)	-0.069*** (0.012)	0.021 (0.065)	-0.012 (0.038)
Lag of others' bid	0.001** (0.001)	0.004*** (0.001)	0.002*** (0.001)	0.001 (0.001)
Period	-0.009*** (0.001)	0.001* (0.001)	-0.003 (0.003)	-0.004 (0.003)
Risky behavior indicator	-0.009 (0.125)	-0.021 (0.067)	-0.153 (0.122)	0.062 (0.091)
Female indicator	0.056 (0.091)	0.024** (0.012)	-0.086* (0.052)	0.115* (0.066)
Age	-0.005*** (0.002)	-0.001 (0.007)	-0.001 (0.007)	-0.005*** (0.001)
Constant	-0.052 (0.193)	-0.661*** (0.151)	-0.141 (0.347)	-0.352*** (0.034)
R^2	0.29	0.43	0.36	0.29
Observations	2592	1728	2160	2160

Robust s.e. clustered at two levels, session and individual, are in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01.

Similar to bids, the overbidding rate is also lower with a partner matching for group size 2 but is not different across matching protocols for group size 3. Similarly, under partner matching protocols, overbidding rates are significantly lower for the smaller group. The effects of the control variables are in line with the literature. These findings are summarized in Result 5.

Result 5. The overbidding rate is lower with a partner matching compared to a stranger matching only for group size 2. For partner matching, the overbidding rate is lower for group size 2.

As we can observe, overbidding rate for Stranger protocol increases with group size. This result can be related to the existing literature of bounded rationality. Following Sheremeta (2013), a higher level of bidding is associated with more restricted rationality. Lim et al. (2014), on the other hand, find more restricted rationality with higher group size while implementing a stranger protocol. Hence, our result of higher overbidding rate with higher group size (without the possibilities of tacit collusion) is consistent with the Lim et al. (2014) result.

6.3 Dispersion in bids

As observed from Table 2 and Figure 1 (right panel), there are differences in bid dispersion across treatments. In particular, the standard deviations of average individual bids are lower in smaller groups. Although understanding the bid dispersion behavior is important for various practical purposes such as contest design, the existing contest literature rarely focus on this issue.[7]

In this study, we propose two measures of dispersion in individual bids: (I) the standard deviation of an individual's bids over 25 periods, and (II) the standard deviation of all individual's bids in each period. Measure I provides us with one observation per individual, whereas measure II provides us with 25 observations for each session, one for each period of the contest.

Once again, we use regressions to test for differences across treatments. We estimate two OLS regressions for measure I, one for each matching protocol, on a dummy for group size 2 and

[7] An exception is Chowdhury et al. (2014) who analyze the phenomenon and term it as 'overspreading'.

a constant. Using measure II, we estimate two panel random effects regressions, again one for each matching protocol, on a dummy for group size 2, a period time trend, and a constant. In all the regressions, we calculate standard errors clustered at the session level. Table 7 presents the coefficient estimates of the group size 2 dummy in each of the four regressions.

Table 7. Dispersion in bids: regression estimates of the group size 2 dummy

Matching	Measure I	Measure II
Partner	-16.013^{**}	-12.676^{***}
	(4.267)	(3.224)
Stranger	-8.153^{***}	-9.290^{***}
	(0.699)	(3.315)
Obs.	90	125
Regression	OLS	Panel RE

Figures in parentheses are robust standard errors clustered on sessions. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 6 shows that the dispersion in bids, with both measures and across matching protocols, is indeed significantly lower in smaller groups. This is summarized below.

Result 6. Dispersion in bids is lower for group size 2 across matching protocols.

We further ran robustness checks on the dispersion measures by running regressions in which we use dispersion as a dependent variable and independent variables are Stranger dummy, Group Size 2 dummy, and an interaction between the two. We have also run regressions for Measure II with lagged variables and the qualitative results remain the same.

We estimate similar regressions (and the robustness checks) to test if dispersion is higher under stranger matching than under partner matching in each group size. The results are reported in Table 8. For group size 2 using Measure I and for both group sizes using Measure II, we do not find any significant difference. However, for group size 3, Measure I is significantly lower under stranger matching.

Table 8. Coefficient estimates of Stranger dummy

	Measure I	Measure II
Group size 3	-9.510**	-5.621
	(2.643)	(4.196)
	[108]	[150]
Group size 2	-1.650	-2.235
	(3.493)	(1.791)
	[72]	[100]
Regression	OLS	Panel RE

Figures in parentheses are robust standard errors clustered on sessions. Figures in brackets are the number of observations in each regression. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The regressions in Table 4 can suggest an explanation for these findings. The regressions show that individuals respond to the (lagged) bids of others more in a partner setting and for smaller groups. In particular, the positive coefficient of the lag of the others' bid suggests that bids move together, thus reducing variation in bids of individuals in such cases.

7. Discussion

Individuals take part in a contest repeatedly in various situations. Two crucial factors that may affect an individual's behavior in such cases are whether he is matched with the same set of players in every repetition (matching protocol), and how many players are engaged in the contest (group size). Thus far, the literature has focused on the effects of group size on bids in a contest, the common finding being that bids are not affected. The issue of matching has received little attention in the literature. Repeated interaction with the same set of players can have reputational issues and could trigger an attempt to collude tacitly. This may become even easier with a small number of players. Hence, matching protocol and group size could have significant joint effects on behavior in contests. An understanding of such effects is important, especially from a contest design point of view. We provide a first formal investigation of these effects in Tullock-type contests.

We employ a 2×2 experimental design to investigate the effects of two most commonly used matching protocols: partner and Random stranger, in two different group sizes: 2 and 3. We find that matching protocol and group size together have significant effects on contest behavior. Average bids do not differ across group size under both matching protocols. This result does not support the equilibrium prediction that bids will increase in smaller groups. We, however, do find that overbidding is lower in smaller groups. Our findings complement and extend Lim et al. (2014) who find under stranger matching that group size does not affect bid level. The matching protocol also does not affect bids or overbidding in groups of size 3. However, a partner matching protocol reduces both the absolute level of bids and overbidding in group size 2. Finally, dispersion in bids is lower in group size 2 but matching protocol does not overall have an effect on bid-dispersion.

Previous findings from market experiments provide an explanation for this phenomenon. It is well known from the experiments on cartels (e.g., Huck et al., 2004; Fonseca and Normann, 2012) that agents can tacitly collude to achieve mutually beneficial outcomes, and further that a decrease in group size increases the likelihood of successful collusion. Our results suggest that contestants are more successful to establish tacit collusion and reduce bids in small group sizes.

Our result has important methodological contribution for contest experiments. For partner protocol each group provides an independent observation, whereas the whole session gives one independent observation in the stranger protocol. Since we find no significant difference in results for 3 player groups across matching protocols, our result prescribes economizing on research budget and using a partner matching while using a group size of 3 or more. This will, however, not be true when one implements a group size of 2.

While designing the experiment, we argued for implementing only 2 and 3 player groups. For stranger matching, Lim et al. (2014) already show the effects of group sizes 2, 4, and 9. We show that due to the lack of tacit collusion, there is no difference in partner and stranger matching for group size 3. If tacit collusion cannot be sustained for 3 players, then behaviorally it cannot be sustained for any group size more than 3 either. So, our design of 2 and 3 player group size turns out to be sufficient.

Successful collusion among players requires coordination of actions. The literature has identified a few ways to promote collusion, specifically to reduce overbidding, in contests. Cason et al. (2012) find that pre-play communication allows players to collude and leads to lower bids. Giving subjects the option to offer side-payments (Kimbrough and Sheremeta, 2013) or to use a randomization device such as the flip of a coin (Kimbrough et al., 2014) allows subjects to even avoid the contest altogether. In the absence of such enforcement mechanisms, we find that matching protocol has a more pronounced effect, in the sense of reducing wasteful overbidding and inefficiency, in smaller groups to increase efficiency.

Croson and Marks (1998) find that the provision of identifiable individual information in an experimental threshold public goods game with partner matching increases average contributions to the public good. Nikiforakis (2010) delineates the types of information that helps cooperation. We extend this literature by establishing that the ability to identify individual behavior (small group size) and repeated play (partner matching) have strong interaction effects that allow players to build reputations and collude effectively even in contests.

There are several dimensions in which our research can be extended. It will be interesting to allow communication and observe the effects of group size in such setting. A detailed experiment to further explore the issue of bid-dispersion is needed and our procedure can be employed there. It would also be very interesting to test the robustness of our results in a field setting. Finally, it still remains an empirical question on how very large group size and matching protocol may interact. We leave these issues for future research.

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Appendix: Instructions

Below we provide the instructions used in this experiment. We provide the instructions for partner treatment; and use appropriate phrases in bracket and shade the phrases that are changed in the stranger treatment.

GENERAL INSTRUCTIONS

This is an experiment in the economics of decision making. This experiment consists of two unrelated parts. Instructions for the first part are given next and the instructions for the second part will be provided after the first part of the experiment is finished.

The instructions are simple. If you follow them closely and make appropriate decisions, you can earn an appreciable amount of money.

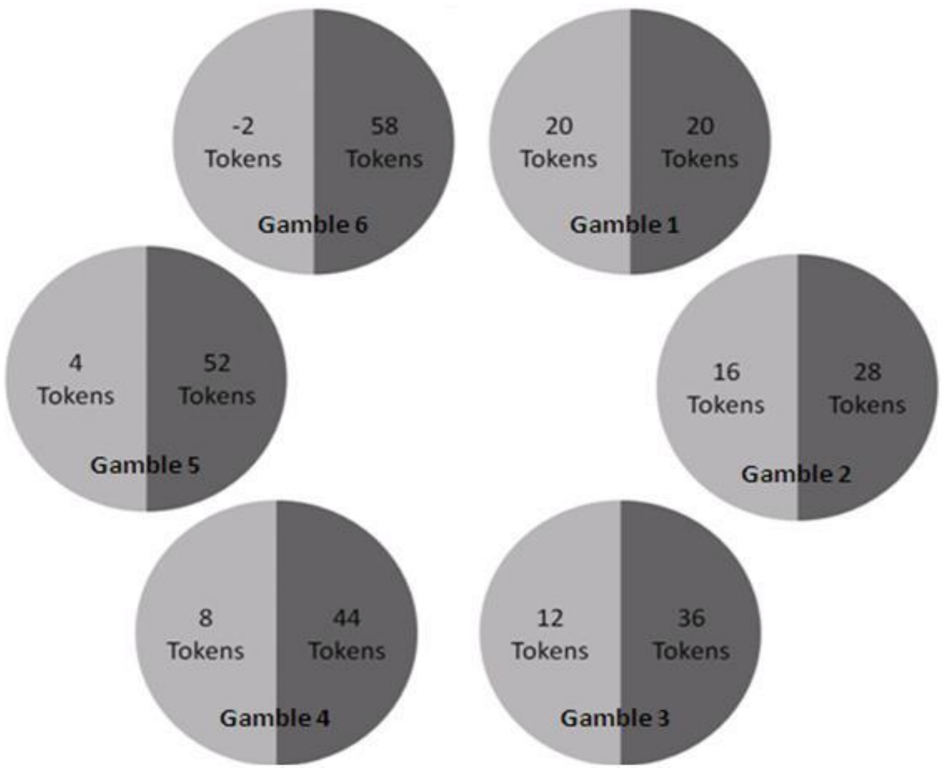
It is very important that you remain silent and do not look at other people's work. If you have any questions, or need assistance of any kind, please raise your hand and an experimenter will come to you. If you talk, laugh, exclaim out loud, etc., you will be asked to leave and you will not be paid.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

Experimental Currency is used in the experiment and your decisions and earnings will be recorded in tokens. At the end of today's experiment, you will be paid in private and in cash. Tokens earned from both parts of the experiment will be converted to Pound Sterling at a rate of:

_1_ token to **_3_** Pence (£0.03).

INSTRUCTIONS – PART 1

In this task, you will be asked to **choose from six different gambles** (as shown below). Each circle represents a different gamble from which you must **choose the one that you prefer**. Each circle is divided in half, with the number of tokens that the gamble will give you in each circle.



Your payment for this task will be determined at the end of today's experiment. A volunteer will come to the front of the room and toss a coin. If the outcome is heads, you will receive the number of tokens in the light grey area of the circle you have chosen. Alternatively, if the outcome is tails, you will receive the number of tokens shown in the dark grey area of the circle you have chosen. Note that no matter which gamble you pick, each outcome has a 50% chance of occurring.

Please select the gamble of your choice by clicking one of the "Check here" buttons that will appear on each circle in the picture Once you have made your choice, please click the "Confirm" button at the bottom of the screen.

For your record, also tick the gamble you have chosen in the above picture.

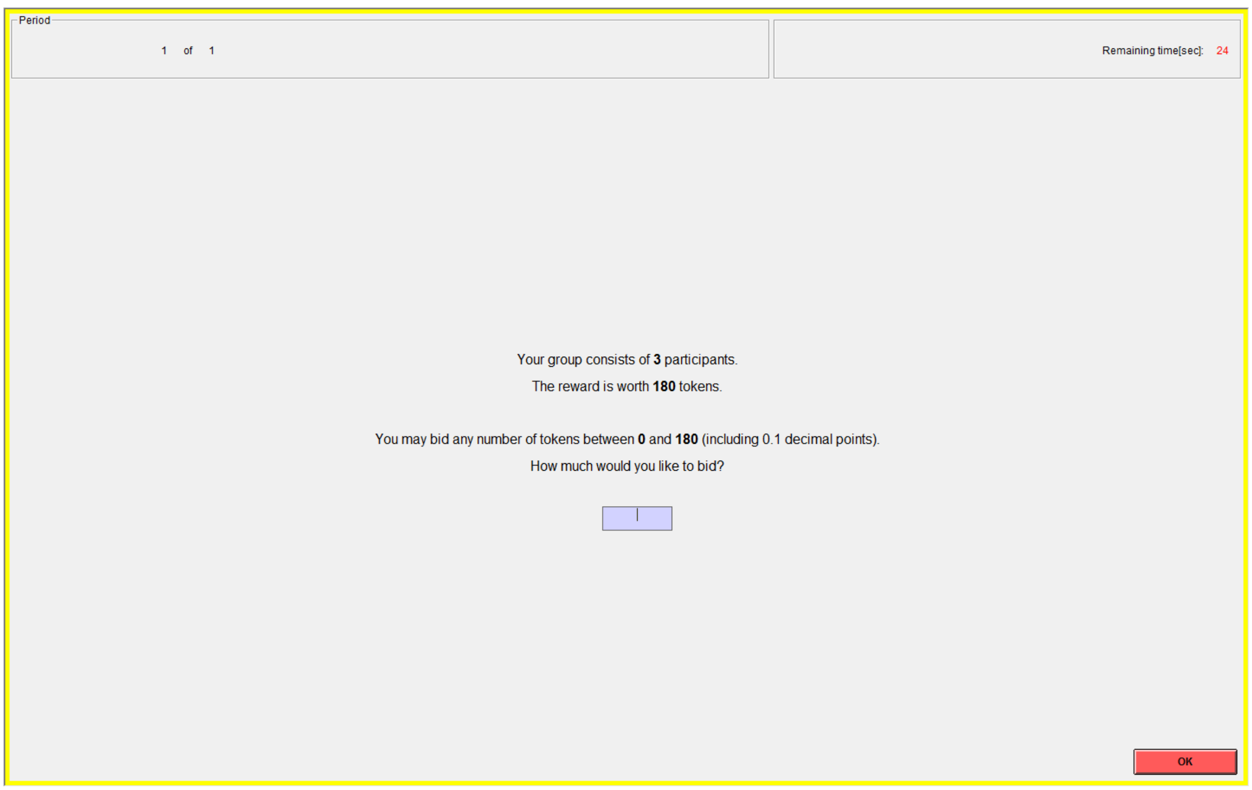
Once everyone has made their decision, this task will end and we will move on to Part 2 of the experiment. Your payment for this task will be decided at the end of today's experiment.

INSTRUCTIONS – PART 2 [For $N = 3$]

YOUR DECISION

This part of the experiment consists of **25** decision-making periods. At the beginning, you will be randomly and anonymously placed into a group of **3 participants**. The composition of your group will remain the same for all 25 periods [*will be changed randomly every period*]. You will **not** know who your group members are at any time.

Each period you will receive an initial endowment of **180** tokens. Each period, you may bid for a reward of **180 tokens**. You may bid any number between **0** and **180** (including 0.1 decimal points). An example of your decision screen is shown below.



YOUR EARNINGS

For each **bid** there is an associated **cost** equal to the bid itself. The cost of your bid is:

Cost of your bid = Your bid

The more you bid, the more likely you are to receive the reward. The more the other participants in your group bid, the less likely you are to receive the reward. Specifically, your chance of receiving the reward is given by your bid divided by the sum of all 3 bids in your group:

$$\text{Chance of receiving the reward} = \frac{\text{Your bid}}{\text{Sum of all 3 bids in your group}}$$

You can consider the amounts of the bids to be equivalent to numbers of lottery tickets. The computer will draw one ticket from those entered by you and the other participants, and assign the reward to one of the participants through a random draw. If you receive the reward, your earnings for the period are equal to your endowment of 180 tokens *plus* the reward of 180 tokens *minus* the cost of your bid. If you do not receive the reward, your earnings for the period are equal to your endowment of 180 tokens *minus* the cost of your bid. In other words, your earnings are:

If you receive the reward: Earnings = Endowment + Reward – Cost of your bid = 180 + 180 – your bid

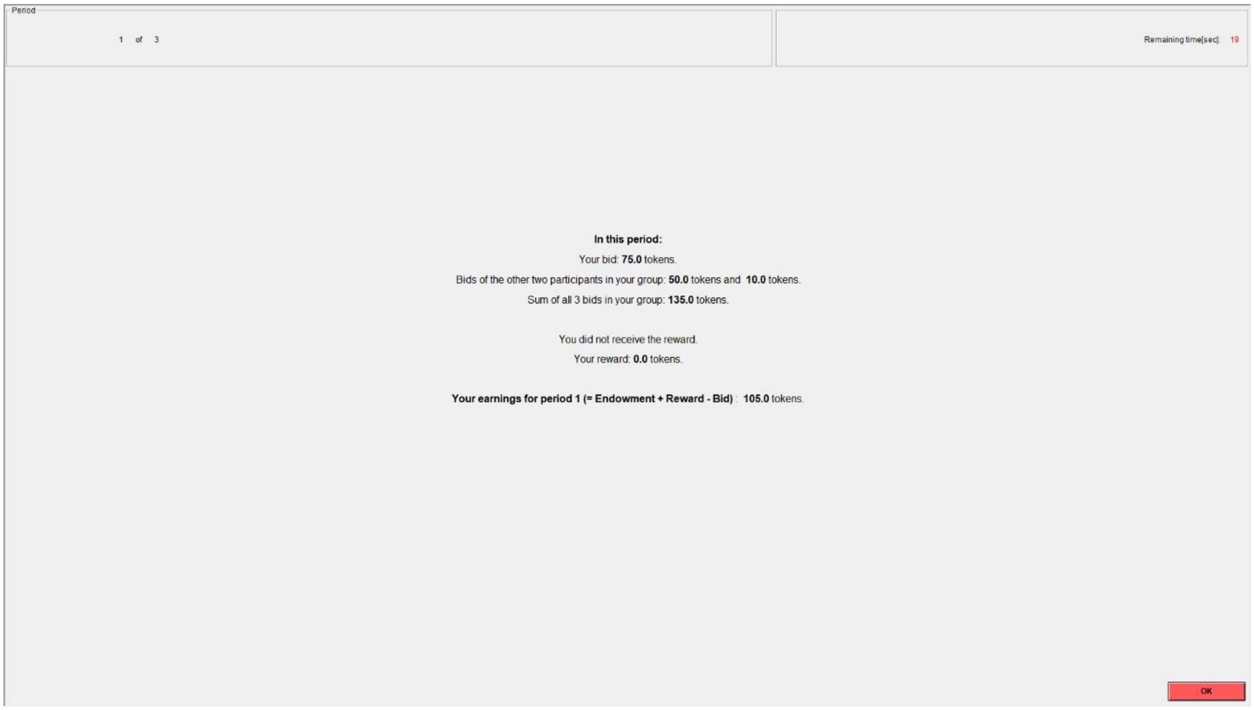
If you do not receive the reward: Earnings = Endowment - Cost of your bid = 180 – your bid

An Example (for illustrative purposes only)

Let's say participant 1 bids 30 tokens, participant 2 bids 45 tokens and participant 3 bids 0 tokens. Therefore, the computer assigns 30 lottery tickets to participant 1, 45 lottery tickets to participant 2 and 0 lottery tickets to participant 3. Then the computer randomly draws **one lottery ticket out of 75** (30 + 45 + 0). As you can see, participant 2 has the **highest chance** of receiving the reward: **0.60 = 45/75.** Participant 1 has **0.40 = 30/75** chance and participant 3 has **0 = 0/75** chance of receiving the reward.

Assume that the computer assigns the reward to participant 1, then the earnings of participant 1 for the period are 330 = 180 + 180 – 30, since the reward is 180 tokens and the cost of the bid is 30. Similarly, the earnings of participant 2 are 135 = 180 – 45 and the earnings of participant 3 are 180 = 180 – 0.

At the end of each period, your bid, the sum of all 3 bids in your group, your reward, and your earnings for the period are reported on the outcome screen as shown below. Once the outcome screen is displayed you should record your results for the period on your **Personal Record Sheet** (page 4) under the appropriate heading.



IMPORTANT NOTES

At the beginning of this part of the experiment [*At the beginning of each period of this part of the experiment*] you will be randomly grouped with another two participants to form a 3-person group. You will not be told which of the participants in this room are assigned to which group.

At the end of the experiment the computer will randomly choose **5 of the 25** periods for actual payment for this part of experiment. You will be paid the average of your earnings in these 5 periods. These earnings in tokens will be converted to cash at the exchange rate of **_1_** token to **_3_** Pence (£0.03) and will be paid at the end of the experiment.

Are there any questions?

Personal Record Sheet

(5 periods from here will be randomly chosen for final payments)

Period	Your bid	Sum of all 3 bids in your group	Your reward	Your earnings for this period
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				

Total Earnings

Period Chosen	Earnings for this period
Total	

Total earnings from table above: ____________ (1)

Average of above earnings: (1) ÷ 5 ____________ (2)

Earnings from Part 1: ____________ (3)

Total earnings (2) + (3) ____________ (4)

Multiply by exchange rate: (4) × 0.03

Total payment for the experiment: £____________

QUIZ

1. Does group composition change across periods in the experiment?

Ans. Yes No

2. What is the value of 1 token in Pence?

Ans. 3 Pence 6 Pence 9 Pence

Questions 3 to 7 apply to the following information.

In a given period, suppose the bids by participants in your group are as follows.

Bid of participant 1: 55 tokens

Bid of participant 2: 70 tokens

Bid of participant 3: 10 tokens

3. What is the chance that participant 1 will receive the reward?

Ans. _______ out of ________

4. What is the chance that participant 2 will receive the reward?

Ans. _______ out of ________

5. What is the chance that participant 3 will receive the reward?

Ans. _______ out of ________

6. If you are Participant 1 and you **did not receive** the reward what are your earnings this period?

Ans. ___________ tokens

7. If you are Participant 2 and you **received** the reward what are your earnings this period?

Ans. ___________ tokens

EXPLANATIONS FOR QUIZ ANSWERS

1. Does group composition change across periods in the experiment?

Ans. No [*Yes*]

2. What is the value of 1 token in Pence?

Ans. 3 Pence

3. What is the chance that participant 1 will receive the reward?

Ans. 55 out of 135.

4. What is the chance that participant 2 will receive the reward?

Ans. 70 out of 135.

5. What is the chance that participant 3 will receive the reward?

Ans. 10 out of 135.

6. If you are Participant 1 and you **did not receive** the reward what are your earnings this period?

Ans. 125 tokens (= Endowment – bid = 180 – 55)

7. If you are Participant 2 and you **received** the reward what are your earnings this period?

Ans. 290 tokens (= Endowment + Reward – Bid = 180 + 180 – 70)