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An Experiment on Lowest Unique Integer Games*

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Abstract

We experimentally study Lowest Unique Integer Games (LUIGs). In a LUIG, N (≥ 3) players submit a positive integer up to M and the player choosing the smallest number not chosen by anyone else wins. LUIGs are simplified versions of real systems such as lottery games and Lowest/Highest Unique Bid Auctions that have been attracting attention from scholars, yet experimental studies are still scarce. Here, we consider four LUIGs with $N = \{3, 4\}$ and $M = \{3, 4\}$. We find that (a) choices made by a majority of subjects over 50 rounds of a LUIG were not significantly different from that in the symmetric mixed-strategy Nash equilibrium (MSE) of the LUIG; however, (b) those subjects who behaved significantly differently from what the MSE predicts won the game more frequently than those who behaved similarly to what the MSE predicts.

Keywords: Lowest Unique Integer Game, Laboratory Experiment

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1 Introduction

We ran laboratory experiments to study how subjects play Lowest Unique Integer Games (LUIGs). In a LUIG, N (≥ 3) players simultaneously submit a positive integer up to M. The player choosing the smallest number that is not chosen by anyone else is the winner. In the cases where no player chooses a unique number, there is no winner.

For instance, suppose there is a LUIG with $N = 3$ and $M = 3$. There are three players, A, B, and C, who each submit an integer between 1 and 3. If the integers chosen by A, B, and C are 1, 2, and 3, respectively, then A wins the game. If the integers chosen by A, B and C are 1, 1, and 2, respectively, then C is the winner. And, as noted, if all of them choose the same integer, there is no winner.

LUIGs are highly simplified versions of real systems such as the Swedish lottery game Limbo where the player who chooses the lowest unique number wins a cash prize (Östling et al., 2011) and Lowest/Highest Unique Bid Auctions (LUBA/HUBA) like the Auction Air or Juubeo websites where players bid, by paying a fixed participation fee, on prizes such as electronic devices or jewelry and either the lowest or highest unique bid wins. These systems differ from LUIGs in that the exact number of players (or participants) is not known when participants are deciding which integer to choose or how much to bid. In addition, unlike with LUIGs or the Swedish lottery, in LUBA/HUBA scenarios, a winner has to pay the amount s/he bids in exchange for the item being auctioned.[1]

These types of real systems have been attracting much attention recently from scholars of various disciplines (Raviv and Virag, 2009; Eichberger and Vinogradov, 2008; Gallice, 2009; Houba et al., 2011; Pigolotti et al., 2012; Rapoport et al., 2007, 2009; Zhou et al., 2015). While the studies mentioned investigate these related systems theoretically and empirically, experimental studies on LUIGs and related systems are still scarce. Östling et al. (2011), Rapoport et al. (2007), and Chmura and Güth (2011) are three experimental studies that are closely related to ours. Östling et al. (2011) experimentally study a version of the Swedish lottery in which subjects were not informed of the exact number of players in the game. Rapoport et al. (2007) experimentally study a

[1]There are other differences depending on the auction site. For example, in a HUBA on the Juubeo website, participants can place multiple bids by paying a small fee for each additional bid and they are immediately informed whether their current bid is the current winning bid.

version of LUBA/HUBA in which subjects were informed of the number of players, N, and strategy space, $\{1, 2, .., M\}$, for $(N, M) \in \{(5, 4), (5, 25), (10, 25)\}$. But unlike our experiment in which the winner receives a fixed payoff regardless of the number chosen, the winner's payoff in Rapoport et al. (2007) is equal to the number he or she has chosen. Chmura and Güth (2011) use experiments to study a three-player minority game.[2] A three-player minority game is structurally equivalent to a LUIG with $N = 3$ and $M = 2$. The experimental method of Chmura and Güth (2011) is, however, different from ours in that they directly elicit a mixed strategy (a probability distribution over two choices) from each subject. In our experiment, each subject submits a pure strategy (i.e., an integer).

We report experimental results on four LUIGs with varying numbers of players, N, and varying sets of integers from which players choose, $\{1, 2, ..., M\}$. Namely, we consider $N \in \{3, 4\}$ and $M \in \{3, 4\}$. Given the exploratory nature of these experiments, the results we report in this paper are descriptive.

We found that (a) choices made by a majority of subjects over 50 rounds of a LUIG were not significantly different from that in the symmetric mixed-strategy Nash equilibrium (MSE) of the LUIG; however, (b) those subjects whose behaviors were significantly different from those under the MSE won the game more frequently.

The rest of the paper is organized as follows: the next section explains the experiment; Section 3 summarizes the results of our experiments; and Section 4 ends the paper with a concluding remark.

2 Experiments

We consider four LUIGs with $N \in \{3, 4\}$ and $M \in \{3, 4\}$. Each subject played two separate LUIGs. We changed either N or M, but not both, between the two games a subject played. Thus, we had eight pairs of games as shown in Table 1. Each LUIG was

[2]In a minority game, three or more odd-numbered players choose one of the two options. This game originates from the "El Farol Bar" problem (Arthur, 1994) which is based on people independently deciding whether to go to a popular bar or not; if too many people independently choose to go to the bar, it will be too crowded and those who stayed at home are better off than those at the bar. The opposite is true when the bar is not too crowded. This problem has been extensively studied both by economists and physicists. See, among others, Challet and Zhang (1997, 1998) for theoretical analyses, and Bottazzi and Devetag (2003, 2007); Chmura and Pitz (2006); Devetag et al. (2011); Platkowski and Ramsza (2003); Linde et al. (2014) for experimental studies with larger numbers of players.

repeated 50 times with the same group of subjects. We call one play of a game a round. There was a non-binding time limit of 15 seconds for choosing an integer in each round. When the time limit was reached, a warning sign appeared on the screen to urge the subject to make a choice. After everyone in the group made their choices, the subjects were informed of the result of the round. The feedback consisted of whether a subject was a winner or not, in addition to the winning number for the round. Subjects were informed that the winning number was set to zero when there was no winner.

Once the 50 rounds of the first LUIG were completed, subjects were re-matched to form another group to play the second LUIG for 50 rounds. Subjects were initially told that they will play two LUIGs with 50 rounds each, but were not informed about the exact game (i.e., N and M) until the start of each game. At the beginning of each game, they were reminded that the other subjects in their group would remain the same during the 50 rounds.

Subjects were paid according to the outcome of one randomly chosen round from each game. The winner of a game received 20 euros in addition to a participation fee of 10 euros. Thus the maximum a subject could earn was 50 euros. Subjects were paid in cash at the end of the experiment.[3]

3 Results

Computerized experiments, implemented using Z-tree (Fischbacher, 2007), took place in January and February 2014 at the Laboratoire d'Expérimentation en Sciences Sociales et Analyse des Comportements (LESSAC), Burgundy School of Business (Dijon, France). 192 students who had never experienced a LUIG experiment participated. There were 24 students in each of the 8 sessions listed in Table 1. A session lasted between 65 and 85 minutes. Out of our 192 subjects, 11 earned 50 euros and 67 earned 30 euros. The remaining 114 subjects earned only the participation fee of 10 euros.

Because a LUIG has many asymmetric pure and mixed-strategy Nash equilibria that are payoff asymmetric, we used the unique symmetric mixed strategy Nash equilibrium (MSE) of the LUIG as our theoretical benchmark. The MSEs for the four LUIGs we

[3] The English translation of the experiment's instructions can be found in the Appendix.

have experimented with are summarized in Table 2.[4] We abbreviate the four LUIGs $(N, M) = (3, 3)$, $(N, M) = (3, 4)$, $(N, M) = (4, 3)$, and $(N, M) = (4, 4)$ using the terms LUIG33, LUIG34, LUIG43, and LUIG44, respectively.

Table 3 shows the relative frequencies of the observed winning numbers in the four LUIGs. For each LUIG, the predicted relative frequencies under the MSE are also reported. Recall that a winning number "0" represents a case without any winner. For three out of four LUIGs, namely, LUIG33, LUIG43, and LUIG44, the observed frequencies of winning numbers are very similar to what the MSE of each game predicts. The major difference between the prediction of the MSE and the experimental outcome is observed in LUIG34 in which "4" was much less frequently the winning number in the experiment compared to the MSE. Overall, however, the MSEs seem to do a good job of organizing aggregate outcomes in the LUIGs we have considered. Next, we tested whether choices made by each subject follow the predictions under the MSE in each LUIG.

Figure 1 shows, in simplexes, the relative submission frequencies for each integer for each subject in the four LUIGs. A point in a simplex represents a subject. The relative frequency of a subject submitting 1 is represented by the height of the point from the edge that is opposite to the apex labeled '1'. The relative frequencies of the subject submitting other integers can be read in the same way in the figure.

For games with $M = 4$, we added together the relative frequencies of submitting the two largest integers because they were small compared to the others under their MSEs. In each panel, the relative frequencies predicted by the MSE are also shown by a "$*$". There are two types of dots: filled and non-filled. The filled dots represent subjects whose choice frequencies were not statistically different from the one predicted by the MSE at 5% significance level according to Kolmogorov-Smirnov (KS) tests. We call these subjects 'MSE subjects' below. Non-filled dots, on the contrary, represent those subjects whose choice frequencies were significantly different from what the MSE predicts. We call these subjects 'non-MSE subjects.' Here we are pooling subjects from all the sessions who played the given LUIG. Thus, in each panel, there are total of 96 dots (subjects).

We find that a majority of our subjects were MSE subjects in each of the four LUIGs.

[4] Östling et al. (2011) provide a succinct algorithm to calculate MSE in LUIGs.

Out of 96 total subjects, the number of MSE subjects in LUIG33, LUIG34, LUIG43, and LUIG44 were 65, 56, 70, and 56, respectively. This finding is similar to Rapoport et al. (2007) who also found that a majority of subjects behaved not significantly differently from what is predicted under the MSE in their experiment of a LUBA with $(N, M) = (5, 4)$.[5]

Since the relative frequencies of numbers chosen by a majority of our subjects were not significantly different from those predicted by the MSE of each LUIG, we checked whether the differences in the MSEs' predictions across LUIGs are also observed in our data. The MSEs summarized in Table 2 show a few clear differences among the four LUIGs: (a) the probabilities of choosing 1 and 2 are very similar for two LUIGs with the same N, that is between LUIG43 and LUIG44, similarly between LUIG33 and LUIG34; (b) given M, the probabilities of choosing 2 are much larger for LUIGs with $N = 4$ than those with $N = 3$, and as a result, the total probabilities of choosing 3 and 4 are much smaller in $N = 4$ games than in $N = 3$ games. Therefore, we expected to observe the significant difference in the frequencies of choices between two LUIGs with the same M but different N, but not between two LUIGs with the same N but different M.

Between two LUIGs with the same M but different N, the distributions of the relative frequencies of the numbers chosen are significantly different between LUIG33 and LUIG43 as well as between LUIG34 and LUIG44 ($p < 0.001$ for both pairs of LUIGs, KS tests). In particular, between LUIG33 and LUIG43, we can see from comparing the panels (a) and (c) of Figure 1, the distributions are more concentrated toward the left edge of the triangle (between the apexes labeled '1' and '2') in LUIG43 than in LUIG33 as predicted under the MSEs of these two LUIGs. Such a pattern, however, is not very clearly observed between LUIG 34 and LUIG44 (panels (b) and (d) of Figure 1).

Between two LUIGs with the same N but different M, the distributions (here we add the relative frequencies of choosing 3 and 4 for $M = 4$ to compare with $M = 3$) are not significantly different between LUIG33 and LUIG34 ($p = 0.229$, KS test) as predicted

[5]Rapoport et al. (2007) also reported that the behaviors of the majority of subjects in LUBAs with $(N, M) = (5, 25)$ and $(N, M) = (10, 25)$ (35 out of 40 and 27 out of 50, respectively) were significantly different from the MSE of the respective game. They found that many of their subjects in $(N, M) = (4, 25)$ continued to choose the same number for a much longer duration than expected under the MSE. A lower fraction of subjects behaving significantly differently from the MSE in the LUBA with $(N, M) = (10, 25)$ than with $(N, M) = (5, 25)$ suggests that the size of M relative to N plays a role in inducing subjects to switch their choices across rounds.

under the MSEs, but are significantly different between LUIG43 and LUIG44 ($p = 0.001$, KS test). If anything, the predictions under the MSEs are the opposite (significant difference between LUIG33 and LUIG34 but not between LUIG43 and LUIG44), thus this hypothesis is only partially supported by our data. The difference between LUIG43 and LUIG44 can be clearly seen in panels (c) and (d) of Figure 1. In the latter, there are many more observations in the area close to the apex labeled '3&4', than the former (area around the apex labeled '3').

Let us diverge from testing whether our subjects behaved according to the MSE of the respective LUIG, and ask how often MSE and non-MSE subjects won the game. Table 4 summarizes, for each LUIG, the average frequencies of "winning" (#wins) as well as the average frequencies of a subject changing his/her choices between two consecutive rounds (#changes) depending on the composition of non-MSE and MSE subjects within a group. As one would expect, non-MSE subjects changed their choices much less frequently than MSE subjects in all four LUIGs. ($p \leq 0.001$ for all four LUIGs, Wilcoxon signed rank, WSR, test). In addition, non-MSE subjects won the game significantly more often than MSE subjects ($p < 0.01$ for all four LUIGs, WSR test).[6] One can also observe that when there are more non-MSE subjects in a group, the difference in the average #wins between non-MSE subjects and MSE subjects is larger in all four LUIGs.

The effectiveness of a non-MSE strategy over a MSE strategy has also been reported in a minority game (Chmura and Pitz, 2006). It seems that in LUIGs as well as in minority games, it pays to be stubborn and to stick with a same number, although such a strategy only works when there are others who frequently change their choices.

4 Concluding Remark

In this paper, we used laboratory experiments to study how subjects play Lowest Unique Integer Games (LUIGs). We consider four LUIGs with the number of players (N) being 3 or 4, and the maximum integer each player can choose (M) being 3 or 4. We found that the choices made by the majority of our subjects over 50 rounds of a LUIG were not significantly different from those predicted under the MSE of the LUIG. We also

[6] These p-values are based on the within-group differences of the average #changes and the average #wins for non-MSE and MSE subjects.

found that those who won more often were those who behaved significantly differently from what was predicted by the MSE by not changing their choices frequently.

Future research may include exploring the effect of changing the amount of feedback subjects receive after each round of a game. For example, in addition to informing subjects about the winning number as we did in our experiment, one can consider informing subjects about all of the submitted numbers to investigate how providing more detailed feedback influences subjects' behavior. Other fruitful avenues for future research include eliciting a mixed strategy directly from subjects as done by Chmura and Güth (2011) for a three-player minority game, or eliciting a behavioral rule (repeated game strategy) as done by Linde et al. (2014) to better understand the behavior of subjects in LUIGs.

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A Instructions

We distributed a handout to our subjects and the experimenter read the script aloud. The handout with the script is available from the authors upon request.

Table 1: Two games played in each session

Session	Game 1	Game 2
1	$(N, M) = (3, 3)$	$(N, M) = (3, 4)$
2	$(N, M) = (3, 4)$	$(N, M) = (4, 4)$
3	$(N, M) = (4, 4)$	$(N, M) = (4, 3)$
4	$(N, M) = (4, 3)$	$(N, M) = (3, 3)$
5	$(N, M) = (3, 4)$	$(N, M) = (3, 3)$
6	$(N, M) = (3, 3)$	$(N, M) = (4, 3)$
7	$(N, M) = (4, 3)$	$(N, M) = (4, 4)$
8	$(N, M) = (4, 4)$	$(N, M) = (3, 4)$

Table 2: Probability of choosing each number under the symmetric mixed-strategy Nash equilibrium for the four LUIGs

	N	M	1	2	3	4
LUIG33	3	3	0.464	0.268	0.268	
LUIG34	3	4	0.458	0.252	0.145	0.145
LUIG43	4	3	0.449	0.426	0.125	
LUIG44	4	4	0.448	0.425	0.126	0.002

Table 3: Relative frequencies of observed winning numbers

a. LUIG 33

	Expr.	MSE
Winning number		
0	12.88%	13.84%
1	40.50%	39.99%
2	26.88%	23.09%
3	19.75%	23.09%

b. LUIG 34

	Expr.	MSE
Winning number		
0	8.88%	11.80%
1	43.31%	40.38%
2	29.18%	22.20%
3	15.94%	12.81%
4	2.69%	12.81%

c. LUIG 43

	Expr.	MSE
Winning number		
0	33.33%	32.91%
1	27.50%	30.09%
2	32.17%	28.60%
3	7.00%	8.40%

d. LUIG 44

	Expr.	MSE
Winning number		
0	27.17%	32.63%
1	32.42%	30.17%
2	30.41%	28.63%
3	8.33%	8.47%
4	1.67%	0.01%

Table 4: Differences of performance with respect to the constitution of players (p-values are from Wilcoxon signed rank test.)

a. $(N, M) = (3, 3)$

			non-MSE		MSE	
#non-MSE	#MSE	#groups	#wins	#changes	#wins	#change
0	3	11			14.45	26.18
1	2	11	17.00	17.37	12.55	28.23
2	1	10	20.70	7.00	4.00	24.90
3	0	0	–	–		

$p < 0.001$ (#wins), $p < 0.001$ (#changes)

b. $(N, M) = (3, 4)$

			non-MSE		MSE	
#non-MSE	#MSE	#groups	#wins	#changes	#wins	#change
0	3	5			14.60	31.87
1	2	15	16.47	17.40	14.47	24.47
2	1	11	19.18	10.00	8.00	27.09
3	0	1	16.00	9.00		

$p = 0.006$ (#wins), $p < 0.001$ (#changes)

c. $(N, M) = (4, 3)$

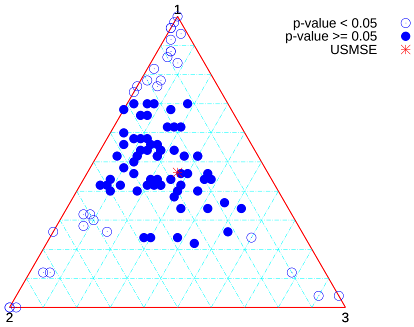
			non-MSE		MSE	
#non-MSE	#MSE	#groups	#wins	#changes	#wins	#change
0	4	4			9.19	22.94
1	3	15	10.60	14.73	7.40	24.53
2	2	4	12.25	8.25	4.50	22.88
3	1	0	–	–	–	–
4	0	1	5.00	7.50		

$p = 0.005$ (#wins), $p < 0.001$ (#changes)

d. $(N, M) = (4, 4)$

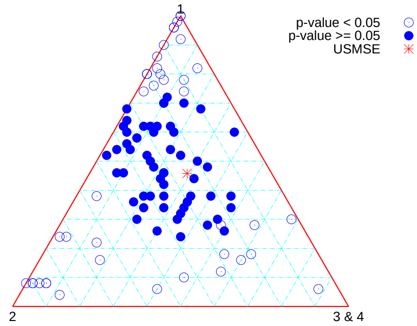
			non-MSE		MSE	
#non-MSE	#MSE	#groups	#wins	#changes	#wins	#change
0	4	5			9.15	29.00
1	3	7	11.29	18.57	8.86	25.43
2	2	6	11.67	14.08	6.25	25.08
3	1	3	10.00	7.67	2.67	22.67
4	0	3	9.50	14.50		

$p = 0.003$ (#wins), $p = 0.001$ (#changes) a.(N,M)=(3,3)



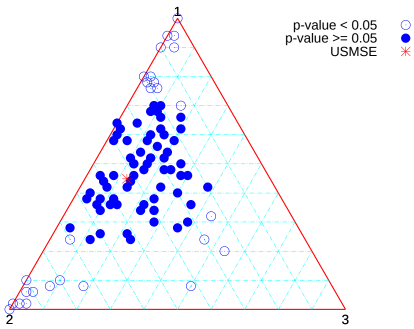
No. of non-MSE=31, No. of MSE=65

b.(N,M)=(3,4)



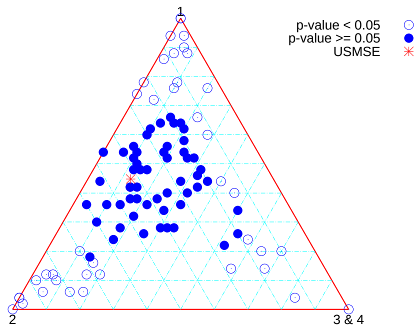
No. of non-MSE=40, No. of MSE=56

c.(N,M)=(4,3)



No. of non-MSE=26, No. of MSE=70

d.(N,M)=(4,4)



No. of non-MSE=40, No. of MSE=56

Figure 1: Distributions of the relative frequencies of each number chosen. Each point corresponds to a subject. Filled circles are those subjects whose choices were not significantly different from those predicted by the MSE (shown in '*') of the game at 5% level by Kolmogorov-Smirnov tests.

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