Appendix for "How Hard to Fight? Cross-Player Effects and Strategic Sophistication in an Asymmetric Contest Experiment"

February 22, 2017

Further Analysis of Comparative Statics and Treatment Effects

The main manuscript specification used interaction terms to estimate treatment-condition-specific comparative statics. Pooling the data across treatment conditions yields similar results, namely strong support for the own value and getting deterred predictions, but weaker support for the doing the deterring predictions. Table A1 shows these results. There is a positive, significant coefficient for the Own Value effect. Also consistent with predictions, there is a negative and significant coefficient for the Getting Deterred variable. However, there is a negative coefficient for Doing the Deterring in the single valuation rounds, which is inconsistent with predictions; this coefficient is positive and insignificant for double valuations.

In the main manuscript we also estimated the effects of each treatment condition on the amount of over-effort, relative to the Nash prediction (Table 3). It included some controls for the Nash effort level, double valuations, experience, and zero value effort. Here, we also include an indicator for male subjects and survey-based personality measures for aggression (Buss and Perry, 1992) and "Machiavellianism" (Dahling, Whitaker and Levy, 2008). Table A2 shows these results. For the main treatment effects, the results are very similar in sign, significance, and magnitude to those reported in the main text. Among the three variables, aggression and being male had negative effects on effort that were significant in one specification apiece. Apart from those two results, none reached conventional levels of significance.

Feedback and Learning/Confounding

Here we provide an additional robustness check that the within-subject feedback treatments (sessions 1-4) are not confounded by learning and an increasing familiarity with the game as the rounds progress.[1] The concern is that subjects tended to decrease their amount of effort in later rounds,

[1] We again thank our reviewers for highlighting this issue.

Table A1: Comparative statics, pooled across treatment conditions

	Single Val. b/se	Double Val. b/se
Own Value	210.78**	295.60**
	(9.76)	(14.28)
Getting	-28.14**	-63.74**
	(6.96)	(8.46)
Doing	-22.82*	13.05
	(11.48)	(17.72)
Constant	109.80**	204.51**
	(7.95)	(9.36)
N	2400	2400
R^2	0.30	0.37

+ $p < .10$, * $p < .05$, ** $p < .01$

then this might mistakenly attribute a decrease in the distance from the Nash prediction, even without the feedback treatment effect.

In the main manuscript, we address this by estimating the between-subjects treatment effects only for Part 1 (in columns 3-4 of Table 3). This allows us to compare behavior with and without feedback, across the same rounds and time periods. The feedback treatment still has a negative, large and significant effect on decreases the distance from the Nash prediction. We also limited our analysis only to (a) sessions which had no feedback or calculator in the first part, BN, and (b) the second part of those sessions. In other words, we can limit analysis the second part of BNBN or BNBF (sessions 1, 4, 6, and 8). This subset of the data allows us to look at the effect of feedback in later rounds, holding constant that every player has already played 16 rounds in the BN condition. This analysis was in in columns 5-6 of Table 3.

Additional analysis also confirms these results. To assess this, we look for a discontinuity in behavior before and after the feedback treatment. If learning explains the change in outcomes, then we should not see a discontinuity. The rate at which behavior converges towards Nash predictions should be steady before and after the treatment. If there is a jump, and behavior gets most closer to Nash predictions after the treatment, then this would suggest that the treatment effect is not an artifact of learning.

Figure A1 shows the percent distance from Nash predictions by period, with Lowess smoothers before and after the feedback treatment. Note that the treatment begins in Round 18, but since the feedback is only provided after participants choose their effort levels, the treatment is administered *after* they make their Round 18 choice. That is why the left side Lowess line includes the efforts from Round 18. There is a slight decline in distance from Nash predictions over time, but there is a distinct jump downwards after the feedback treatment is administered. This jump is also apparent in Figure A2 which zooms in on the break point, only including Rounds 12-23. The distinct break

Table A2: Treatment effects with additional controls

	All Data	Part 1 only	Part 2 after BN
	b/se	b/se	b/se
Feedback	-68.81**	-54.35*	-133.89**
	(17.94)	(20.85)	(45.98)
Calculator	-44.82+	-37.94	
	(23.30)	(23.02)	
Feed. X Calc.	56.35*	50.55+	
	(23.48)	(29.47)	
Nash effort	-0.13**	-0.20**	-0.05
	(0.04)	(0.04)	(0.05)
Double valuation	-10.94*	-14.21*	-12.32
	(4.91)	(6.23)	(10.25)
Experience	-1.01*	-3.61**	-3.63*
	(0.39)	(0.98)	(1.63)
Zero value effort	0.23**	0.32**	0.11*
	(0.05)	(0.06)	(0.04)
Male	-27.94+	-32.63+	-46.64
	(15.62)	(18.34)	(31.11)
Risk Scale	-2.79	-4.51	-35.84
	(25.74)	(30.58)	(42.66)
Aggr. Scale	-13.84	-17.95	-70.64+
	(21.30)	(26.18)	(38.67)
Constant	169.48**	199.16**	255.32**
	(26.47)	(27.98)	(63.02)
N	4,800	2,400	928
R^2	0.06	0.06	0.09

+ $p < .10$, * $p < .05$, ** $p < .01$

Figure A1: Percent Distance from Nash by Round

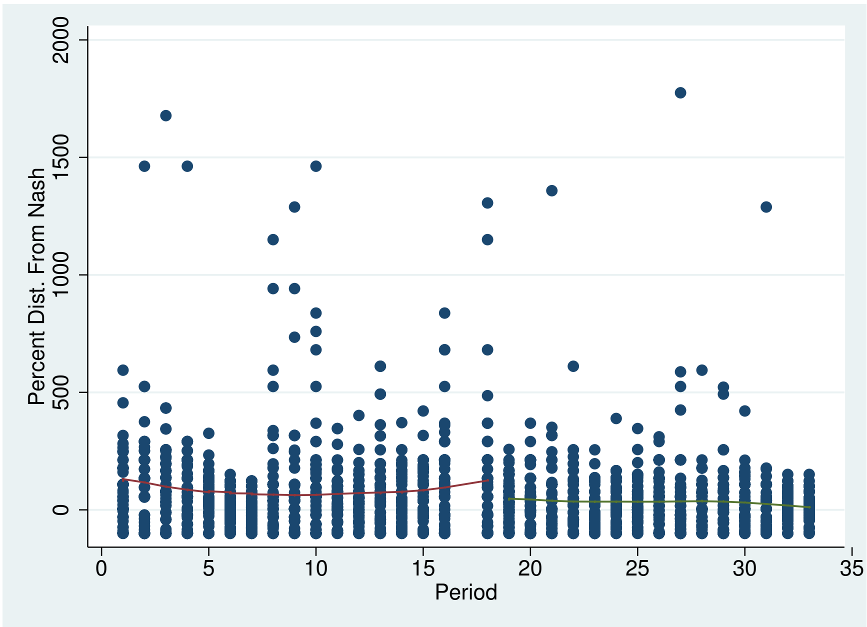
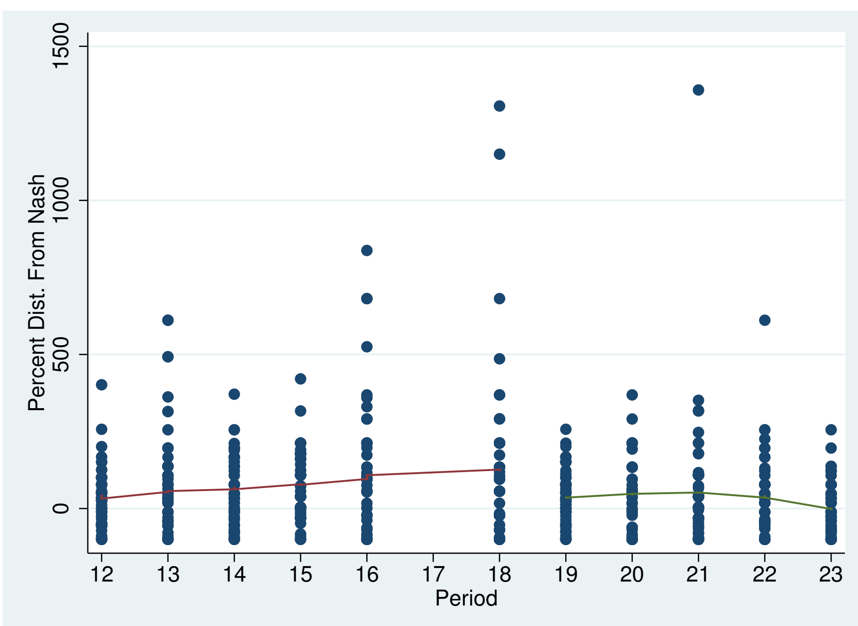


Figure A2: Percent Distance from Nash by Round, Plus/Minus Five Round Window



supports the argument that the feedback treatment effect is not simply an artifact of learning over time.

Strategic Sophistication and the Level k Model

To demonstrate how our conception of strategic sophistication is different from that of the level k model, Figure A3 shows a each subject's level of sophistication as measured by the level k model, broken down by whether the subject's behavior tended to be consistent with all, none, or one of the comparative static predictions.[2] The subjects' levels are poorly correlated with the degree to which the subject displayed behavior consistent with comparative static predictions. The subjects whose behavior was consistent with both comparative static predictions are only estimated to play at a very slightly higher level of strategy according to the level k model. Among the subjects whose behavior was consistent with none of the comparative static predictions, the average level was 2.097. Among the subjects whose behavior was consistent with at least one of the comparative statics, their estimated level only very slightly higher, 2.103.

Variation in Search Quality

This section describes our measures of search quality in greater detail. For a set of minimal measures of search quality, we code whether each click or guess yields net positive expected utility, EU_i, relative to purchasing 0 tickets and ensuring a payoff of 1000 points. As described in the main text, Own Positive indicates whether $EU_i > 1000$ for subject i (the subject using the calculator), Opponent Positive indicates whether the guess yields positive expected utility $EU_j > 10000$ for i's opponent j, and Both Positive indicates searches where both $EU_i > 1000$ and $EU_j > 1000$.

Another measure of search quality relates to the direction of search. Let $g_k = (e_{ik}, e_{jk})$ denote subject i's k-th guess in any given round. The direction of search refers to the angle of the difference vector $\Delta g = g_{k+1} - g_k$, which we measure in degrees (from $0°$ to $360°$). If a subject searches the strategy space by holding the opponent's effort constant $e_{j,k} = e_{j,k+1}$ while varying her own effort $e_{i,k} \neq e_{i,k+1}$, the direction of search will be *horizontal*. Conversely, if a subject holds her own effort constant $e_{i,k} = e_{i,k+1}$ while varying her guesses about her opponent's effort $e_{j,k} \neq e_{j,k+1}$, the direction of search will be *vertical*. Horizontal searches reflect a subject's attention to her own payoffs, which is individually rational in the sense of maximizing one's own payoffs, while vertical searches reflect attention to her opponent's payoffs and reflect strategic rationality in the sense of forming rational expectations about opponent behavior. We allow for two levels of error tolerance in how we classify horizontal and vertical searches, with a relatively narrow tolerance of $\pm 10°$ and a wider tolerance of $\pm 22°$. We then code each guess after the first ($k > 1$) as horizontal, vertical, or diagonal (neither horizontal nor vertical).

[2] We calculated levels by assuming that a level zero player randomized between zero and her valuation. The results are similar if we assume that level zero players randomize over the interval zero to 1,000, the maximum tickets they can buy.

Figure A3: Comparative Statics vs. Level K

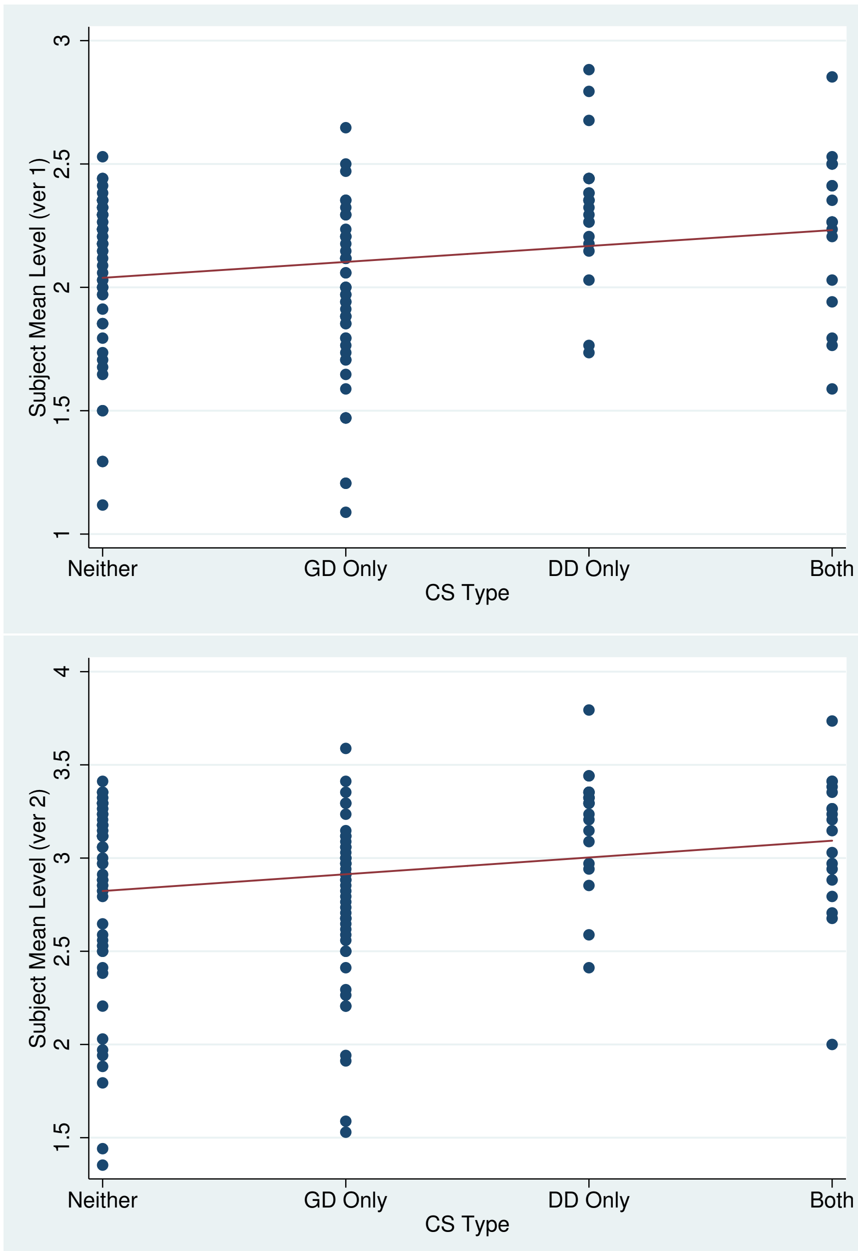


Table A3: Measures of search quality

	Total		Subject-period		Subject	
	Mean	N	Mean	N	Mean	N
Own Positive	.53	12,010	.59	1,179	.37	58
Opponent Positive	.50	12,010	.53	1,179	.34	58
Both Positive	.32	12,010	.35	1,179	.23	58
Horizontal ($\pm 10°$)	.30	10,831	.30	1,034	.18	58
Horizontal ($\pm 22°$)	.40	10,831	.40	1,034	.24	58
Vertical ($\pm 10°$)	.23	10,831	.24	1,034	.14	58
Vertical ($\pm 22°$)	.32	10,831	.32	1,034	.19	58
Distance	121.7	10,831	172.9	1,034	103.6	58
Searches	–	–	10.2	1,179	6.5	58

We find that the quality of subjects' searches according to these measures tends to be fairly poor. Table A3 describes the averages for our measures of search quality along with the distance between each guess and the total number of guesses. We present the overall means, the subject-period level means, and the subject-level means. The results do not differ much by level of aggregation.

According to our positive expected payoff measures, at most half of subjects' searches in the *Calculator* treatment can be classified as minimally rational. 53.1% of guesses involve positive expected values for the subject's own payoffs and 50.8% of guesses involve positive expected values for their opponent's payoffs. However, fewer than one-third of guesses (32%) involve positive expected payoffs for both the subject and their opponent. While we would expect to see that initial searches within a period yield net negative expected payoffs, we also thought that minimally rational search behavior would move quickly towards areas of the strategy space where both players receive positive expected utility. The prevalence of negative expected payoff guesses suggests to us that most searches are of low quality.

We also find that horizontal and vertical searches comprise half of the guesses entered into the calculator. While we might expect some searches to be diagonal, systematic guesses along one of the dimensions to search for a player's best reply appear to be rare. Searches along one dimension also tend to be horizontal (31% of all searches using the $10°$ tolerance) rather than vertical (20%), which suggests that subjects tend to focus on their own payoffs rather than their opponents. This may reflect a failure of subjects to engage in any kind of meaningful strategic reasoning.

To assess whether the quality of search affects behavior, we estimate several regression models with our search measures as right-hand side variables. Table A4 to Table A6 show various specifications for these regressions. The first table uses all parts of all sessions that included a calculator. The second and third tables limit analysis to sessions without and with feedback, respectively. For each table, the first column uses the Own/Opponent/Both Positive variables. The second column uses the total number of searchs in the Own/Opponent/Both Postive regions. The third column uses the variables describing the direction of the search. The fourth column uses variables describing the total amount of searching the player conducted as well as the distance she covered in her search. The final column uses the Own/Opponent/Both Positive variables and the search direction variable.

The variables indicating searches in the Both Positive region consistently have negative coefficients and are statistically significant in most specifications. This indicates that subjects searching in this region generally exerted less over-effort compared to subjects who searched in the regions where only one player (or neither player) received a positive payoff. This is consistent with the idea that better searching leads to better play.

The variables indicating vertical and horizontal searches have positive coefficients. Players who searched only in one dimension, as opposed to diagonal searches that varied both players' effort levels, tended to exert higher levels of over-effort. This is also consistent with the idea that better searching yields better play, although these results were not statistically significant.

More extensive searching, either in terms of distance or the number of clicks, did not generally improve play. Players searching a greater distance exerted higher degrees of over-effort. The total number of clicks had an inconsistent effect on over-effort.

References

Buss, Arnold H. and Mark Perry. 1992. "The Aggression Questionnaire." *Journal of Personality and Social Psychology* 63(3):452.

Dahling, Jason J, Brian G Whitaker and Paul E Levy. 2008. "The development and validation of a new Machiavellianism scale." *Journal of Management* 35(2):219–257.

Table A4: Effect of search quality on effort (all)

	(1)	(2)	(3)	(4)	(5)
	b/se	b/se	b/se	b/se	b/se
Feedback	-10.83	-12.37	-11.02	-10.83	-7.13
	(15.54)	(14.77)	(16.10)	(14.71)	(14.74)
Nash effort	-0.06	-0.09+	-0.13*	-0.13*	-0.05
	(0.05)	(0.05)	(0.06)	(0.06)	(0.05)
Double val.	-8.18	-5.50	-3.98	-5.63	-9.60
	(8.17)	(8.44)	(8.92)	(9.06)	(8.21)
Experience	-0.71	-0.76+	-0.88+	-0.69	-0.57
	(0.45)	(0.45)	(0.50)	(0.46)	(0.44)
My Pos. Search	31.13*				1.29
	(12.61)				(25.45)
Opp. Pos. Search	35.57				15.27
	(22.05)				(27.72)
Both Pos. Search	-123.69**				-108.85**
	(24.26)				(31.69)
My Pos. Search (num)		0.67			
		(0.47)			
Opp. Pos. Search (num)		0.58			
		(0.92)			
Both Pos. Search (num)		-4.83**			
		(1.46)			
Horiz. (10 deg.)			7.47		43.43
			(20.59)		(32.24)
Vert. (10 deg.)			21.01		45.90*
			(18.09)		(22.11)
Distance				0.11*	0.11*
				(0.05)	(0.05)
Total clicks				-0.27	-0.33
				(0.38)	(0.38)
Constant	93.31**	100.89**	98.73**	91.83**	79.16**
	(29.40)	(26.76)	(28.34)	(24.90)	(25.28)
N	1,856	1,856	1,711	1,711	1,711
R^2	0.05	0.03	0.02	0.03	0.07

+ $p < .10$, * $p < .05$, ** $p < .01$

Table A5: Effect of search quality on effort (no feedback)

	(1)	(2)	(3)	(4)	(5)
	b/se	b/se	b/se	b/se	b/se
Nash effort	-0.14	-0.16	-0.19	-0.17+	-0.10
	(0.08)	(0.10)	(0.11)	(0.10)	(0.08)
Double val.	-12.96	-12.83	-13.79	-18.69	-18.96
	(12.21)	(12.62)	(10.93)	(13.97)	(12.21)
Experience	-5.01+	-4.69+	-4.79+	-3.83+	-4.06+
	(2.46)	(2.33)	(2.56)	(2.12)	(2.20)
My Pos. Search	15.69				-8.91
	(29.42)				(51.35)
Opp. Pos. Search	-17.57				-20.90
	(28.33)				(39.36)
Both Pos. Search	-77.67*				-76.23
	(33.24)				(46.36)
My Pos. Search (num)		0.80			
		(1.02)			
Opp. Pos. Search (num)		-1.28			
		(2.21)			
Both Pos. Search (num)		-3.92			
		(3.17)			
Horiz. (10 deg.)			25.28		68.43
			(46.01)		(70.23)
Vert. (10 deg.)			24.34		49.57
			(32.42)		(36.23)
Distance				0.16	0.16
				(0.14)	(0.14)
Total clicks				-1.79	-1.80
				(1.31)	(1.37)
Constant	159.39**	151.35**	138.44**	135.72**	129.04**
	(56.27)	(47.53)	(40.22)	(29.86)	(30.99)
N	448	448	408	408	408
R^2	0.08	0.06	0.04	0.07	0.12

+ $p < .10$, * $p < .05$, ** $p < .01$

Table A6: Effect of search quality on effort (feedback)

	(1)	(2)	(3)	(4)	(5)
	b/se	b/se	b/se	b/se	b/se
Nash effort	-0.03	-0.07	-0.11+	-0.11+	-0.03
	(0.05)	(0.05)	(0.06)	(0.06)	(0.05)
Double val.	-8.04	-4.41	-2.96	-4.09	-9.24
	(9.39)	(10.19)	(10.99)	(10.83)	(9.77)
Experience	-0.40	-0.48	-0.62	-0.50	-0.37
	(0.47)	(0.48)	(0.55)	(0.51)	(0.50)
My Pos. Search	31.38**				5.87
	(11.43)				(19.63)
Opp. Pos. Search	54.81+				37.55
	(29.12)				(36.95)
Both Pos. Search	-138.87**				-127.82**
	(31.76)				(41.57)
My Pos. Search (num)		0.64			
		(0.49)			
Opp. Pos. Search (num)		0.99			
		(1.16)			
Both Pos. Search (num)		-4.90**			
		(1.73)			
Horiz. (10 deg.)			0.16		28.72
			(18.67)		(27.00)
Vert. (10 deg.)			20.92		38.09
			(22.13)		(24.78)
Distance				0.09*	0.09**
				(0.03)	(0.03)
Total clicks				0.03	-0.03
				(0.31)	(0.27)
Constant	71.68**	80.34**	81.82**	75.05**	65.82**
	(17.71)	(17.63)	(18.54)	(18.07)	(17.54)
N	1,408	1,408	1,303	1,303	1,303
R^2	0.04	0.02	0.01	0.02	0.06

+ $p < .10$, * $p < .05$, ** $p < .01$

Appendix: Instructions for Calculator Treatment

Instructions

General Information

This is an experiment on the economics of strategic decision-making. XXX has provided funds for this research.

You will be paid in cash for your participation, and the exact amount you receive will be determined during the experiment and will depend partly on your decisions, partly on the decisions of others, and partly on chance. You will be paid your earnings privately, meaning that no other participant will find out how much you earn. These earnings will be paid to you at the end of the experiment along with the $5 participation payment.

Pay attention and follow the instructions closely, as we will explain how you will earn money and how your earnings will depend on the choices that you make. Each participant has a printed copy of these instructions, and you may refer to them at any time.

If you have any questions during the experiment, please raise your hand and wait for an experimenter to come to you. Please do not talk, exclaim, or try to communicate with other participants during the experiment. Also, please ensure that any phones or electronic devices are turned off and put away. Participants intentionally violating the rules will be asked to leave and may not be paid.

Parts, Rounds, and Matching

This experiment consists of several parts. We will explain the instructions for each part before beginning that part. In each part, you will make decisions in one or more rounds.

In every round you will be **randomly matched** with one other participant. You will not know the identity of the other participant you are matched with in any round, and your earnings for each round depend only on your action in that round and the action of the participant you are matched with in that round.

Your earnings during each round are denominated in points, which we will convert to cash at a rate of $1 for every 75 points. We will **randomly select one round to count** for payment from the entire session, and each round is equally likely to be selected. The points you receive in that round will be used to calculate your payment for the experiment. You should think of each round as a separate decision task.

Appendix: Instructions for Calculator Treatment

Part 1. Lottery Contest Game

In each round, you and the other participant you are matched with will compete for a prize. This prize will be worth X points to you and Y points to the other player. These amounts may be different in every round, and during the round both you and the other player will know exactly what the prize is worth to each of you.

You will compete for the prize by purchasing "contest tickets." At the beginning of each round, you have 1,000 points. You can use these points to purchase contest tickets at a cost of 1 point per ticket. You can purchase up to 1,000 of these tickets. Any points you do not spend on contest tickets will be added to your point balance for the round.

Your payoff will be the number of tickets you keep plus, if you win, the value of the prize. If you buy T tickets and the prize is worth X points to you, then:

$$\text{Your payoff if you win} = X + 1000 - T$$

$$\text{Your payoff if you do not win} = 1000 - T$$

For example, suppose you buy 300 contest tickets and the prize is worth 600 points to you. Thus, you kept 700 points from your original 1,000 points. If you win the prize, then you would earn 600 points from the prize plus the 700 points you kept for a total earning of 1,300 points for the round. If you do not win the prize, then you would earn 700 points for the round. Of course, this is just one example of how to compute your possible earnings.

The winner of the prize is determined by a lottery contest. The lottery contest works as follows. As soon as everybody has chosen how many contest tickets to buy, the computer will randomly select one winning ticket (separately for each group) to determine whether you or the other player wins the prize. Your chance of winning the prize in the round depends on how many contest tickets you buy and how many contest tickets the other player buys. More specifically, your chance of winning is equal to your share of the total tickets bought in that round:

$$\text{Chance of winning prize} = \frac{\text{Your tickets}}{\text{Your tickets} + \text{Other player's tickets}}$$

For instance, if you and the other player each bought the same number of contest tickets, each of you has a 50 percent share of the lottery tickets and therefore a 50 percent chance of winning. If you buy twice as many contest tickets as the other player, you have two-thirds of the contests tickets (and therefore a two-thirds chance of winning) while the other player has a one-third share of tickets (and a one-third chance of winning).

Thus, your chances of winning the prize increase with the number of contest tickets you buy. Conversely, the more contest tickets the other player buys, the higher the probability that the other player wins. If only one player buys contest tickets, then that player will win the prize for sure. If nobody buys any contest tickets, no contest takes place and no one wins the prize.

Appendix: Instructions for Calculator Treatment

After everyone chooses how many tickets to buy in each round, we will proceed to the next round. You will not find out the results from any round of Part 1 until all rounds of Part 1 are completed.

Payoff Calculator

In every round, you will have access to a payoff calculator to help you make your decision (as shown in the first picture on the next page). To use the payoff calculator, click on a point inside the white square on the right side of the screen. You can think of the coordinates of the point you click as guesses about the possible amounts of tickets that you and your opponent might buy. The x-coordinate (along the horizontal dimension) corresponds to the number of tickets you might buy for yourself. The y-coordinate (along the vertical dimension) corresponds to the number of tickets you think the other player might buy.

For each time you click inside the white square, the results of the calculation will appear in a list on the left side of the screen as follows. The first two columns show you the numbers of tickets you entered into the calculator. The rest of the columns (from left to right) show you three useful quantities calculated for you:

- Your probability of winning the prize
- The "expected value" of your payoff
- The "expected value" of the other player's payoff

The expected values describe the average number of points you might receive based on the tickets purchased in that round. The expected values are calculated using the following formula:

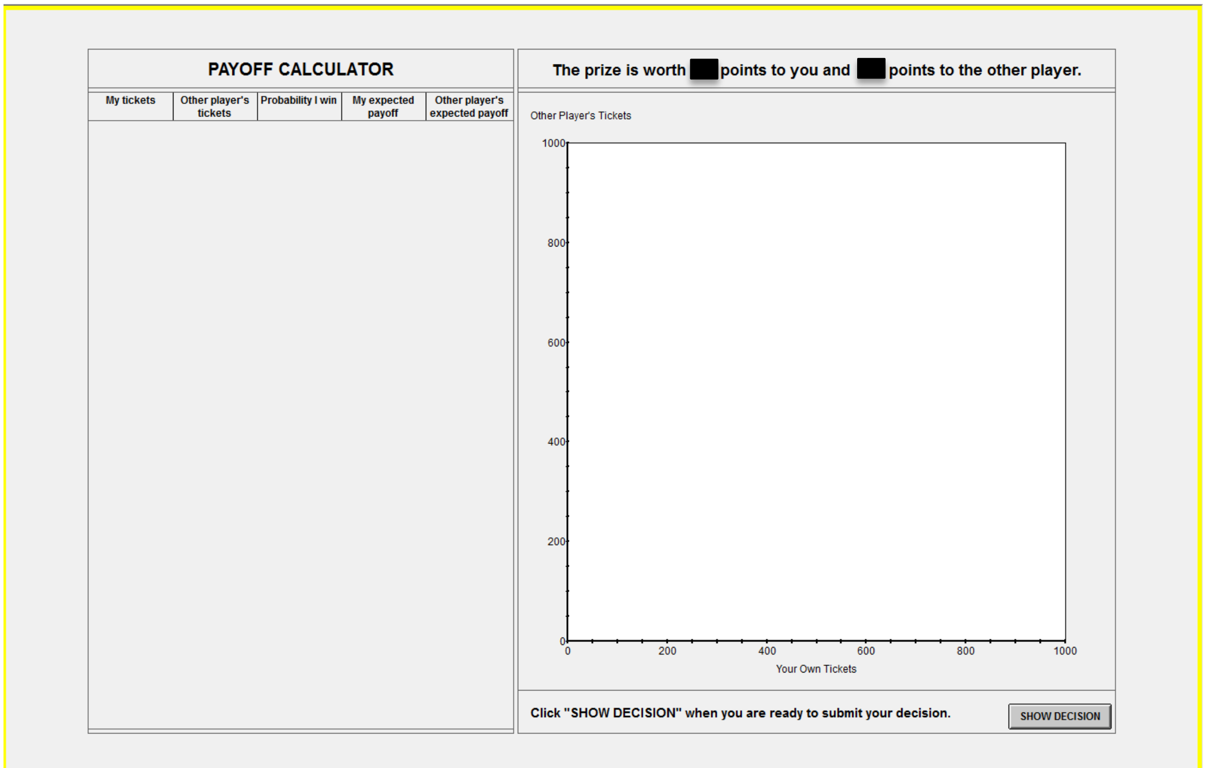
$$\text{Expected Value } = (\text{Prob. of win})(\text{Points from win}) + (\text{Prob. of loss})(\text{Points from loss})$$

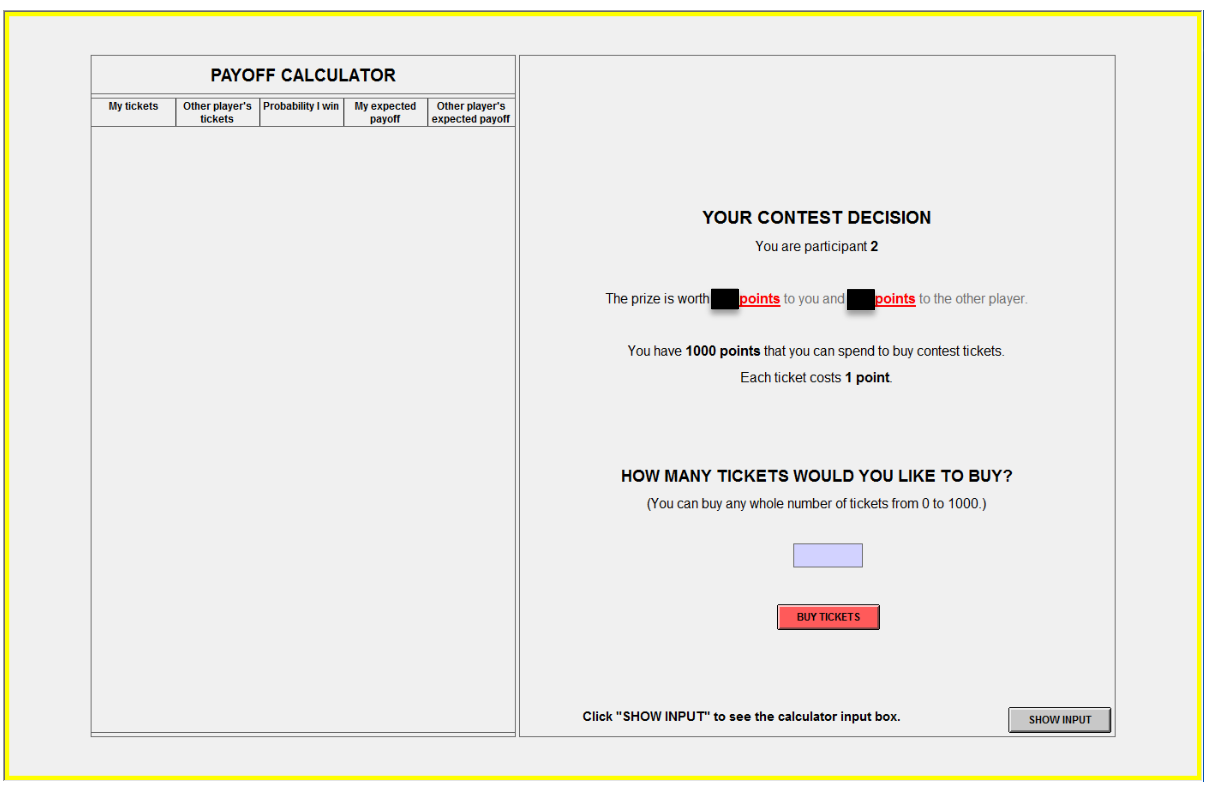
The calculator will show you the results of all the calculations you made in that round, and you should use it as often as you need to before making a decision.

When you are ready to purchase contest tickets, click on the "Submit Decision" button in the bottom-right of the screen. When you click this button, you will see the Decision Input area on the right side of your screen (as shown in the second picture). This button will appear 20 seconds after the round begins so that you have some time to use the calculator. Note that you can also return to the calculator input box from the Decision Input screen and continue to use the payoff calculator as often as you like until you submit your decision. There is no time limit for using the calculator. To purchase your tickets in the Decision Input screen, enter a number in the box on the right side of the screen and then click on the red "Buy Tickets" button.

Appendix: Instructions for Calculator Treatment

Sample screens





<u>Appendix: Instructions for Calculator Treatment</u>

Instruction Quiz

Before we begin the experiment we would like you to answer a few questions to make sure you understand how the lottery contest game works. Please answer these questions on your computers. You will receive immediate feedback once you answer all of the questions. We will then begin the experiment when everyone has answered these questions.

1. Suppose the prize is worth 700 to you. If you purchase 100 tickets, how many points will you earn if you <u>win</u> the prize?
    a. 600
    b. 900
    c. 1600
    d. 1700

2. If the prize is worth 400 to you and you purchase 200 tickets, how many points will you earn if you <u>do not win</u> the prize?
    a. 200
    b. 400
    c. 600
    d. 800

3. If you purchase 100 tickets and the other player purchases 400 tickets, what is your chance of winning the prize?
    a. 100 / 400
    b. 300 / 400
    c. 100 / 500
    d. 400 / 500

4. If you purchase 300 tickets and the other player purchases 100 tickets, what is your chance of winning the prize?
    a. 100 / 300
    b. 200 / 300
    c. 100 / 400
    d. 300 / 400

Appendix: Instructions for Calculator Treatment

Part 2. Lottery Contest Game with Feedback

You will play the Lottery Contest Game in Part 2 exactly the same way you did in Part 1. The only difference is that between rounds, you will find out which player won the contest, how many tickets the other player purchased, and the number of points you earned during the round. During the round, you will also be able to view the results of all previous rounds you played, and you can switch between this history and the payoff calculator when making your decision in each round.