Online Appendices for "Arms Races and Conflict: Experimental Evidence"

Appendix A. Experiment Instructions

[Note: this appendix presents the experimental instructions for all treatment. Below, we first present the instructions for the Base, Hidden and Asymmetry treatments, along with their main screenshots. Capitalized texts are the additional words for the Hidden Treatment and italicized texts are the additional words for the Asymmetry Treatment.]

Welcome to this experiment on decision-making. You have earned $5 for showing up on time. Please read the following instructions carefully. During the experiment, you will be asked to make a number of decisions. Your decisions and the decisions of other participants will determine your cash earnings. Your anonymity is ensured for the decisions you make. The experiment will consist of 12 rounds. No communication during the experiment is allowed. Final payment will be rounded to the nearest 10 cents. If you have a question, please raise your hand.

Matching: In each of the 12 rounds all participants will be matched in pairs. The pairs will be the same for all rounds. So you will be matched with another person and you will stay matched to this person throughout the whole experiment. You will NOT be rematched. [*In each pair, the computer will randomly select one person to be person X and the other person Y.]*

Lotteries: In each round, you can earn money by choosing between lotteries: you will see on your screen two lotteries displayed, lottery A and lottery B. You can choose either lottery A or B. After you made the choice, you can spin the wheel and the chosen lottery will be played out. You will see on your screen the lottery outcome and the amount earned will be added to your total earnings. You have a start fund of $5.

Tokens: Apart from the lottery decisions you have to make in each round, both you and the person you are matched with will have the option to invest $1 to buy a token *in each round*. That is, in each round, you will decide whether or not to buy a $1 token. [*Person X starts with 0.5 token and person Y starts with 0 token in round 1.*] The money spend in tokens is non-refundable and tokens are accumulated from round to round. Note that the token you have bought in one round will only be effective for the next round. For example, if you already have 2 tokens at the beginning of a round and decide to buy one more token in this round, it means you only have 2 tokens for this round, and you will have 3 tokens for the next round.

Deactivation: In each round, you will see your own and the other person's token balance, that is, the numbers of tokens bought up till this round. [IN EACH ROUND, YOU WILL ONLY SEE THE NUMBERS OF TOKENS YOU BOUGHT UP TILL THIS ROUND, AND YOU WILL NOT KNOW OTHER PERSON'S TOKEN.] Both of you can decide whether to press the "deactivate" or "not deactivate" button. Pressing the "deactivate" button costs $1.5. You only have one chance to press the "deactivate" button.

Depending on the current token balance, pressing the "deactivate" button has different consequences for the other person and yourself.

If you have more tokens than the other person and you press "deactivate", the other person will be deactivated, meaning:

1. All earnings so far (including the start fund) of the other person will be set to $0.
2. All payoffs in the future lotteries for the other person will be divided by 10.
3. The other person will not be able to deactivate you in future rounds.

[Note: the following condition about equal number of tokens is irrelevant and therefore absent in the Asymmetry treatment.]

If you and the other person have equal number of tokens and you press "deactivate", both the other person and you will be deactivated, meaning:

1. All earnings so far (including the start fund) for the other person and you will be set to $0.
2. All payoffs in the future lotteries for the other person and you will be divided by 10.

If you have fewer tokens than the other person and you press "deactivate", only you will be deactivated, meaning:

1. All earnings so far (including the start fund) for you will be set to $0.
2. All payoffs in the future lotteries for you will be divided by 10.
3. You will not be able to deactivate the other person in future rounds.

In summary, once a person is deactivated either directly by the other person or indirectly by his/her own action, it will wipe out his/her total earnings from all previous rounds and decrease the potential earnings from future rounds by 90%. Furthermore, a deactivated person will not be able to deactivate the other person.

There are two further rules:

a) If you and the other person press the "deactivate" button in the same round, the rules described above apply to both you and the other person. But no one can be deactivated twice.
b) If no one has been deactivated after the last (12^{th}) round, you will have the option to press the "deactivate" button one last time though there will be no lottery decision to make any more.

The 12 lottery choices

Choice if you have not been deactivated

No.	Lottery A	Lottery B
1	15% of \$2.70, 85% of \$2.30	15% of \$3.40, 85% of \$1.70
2	30% of \$2.70, 70% of \$2.30	30% of \$3.40, 70% of \$1.70
3	45% of \$2.70, 55% of \$2.30	45% of \$3.40, 55% of \$1.70
4	60% of \$2.70, 40% of \$2.30	60% of \$3.40, 40% of \$1.70
5	75% of \$2.70, 25% of \$2.30	75% of \$3.40, 25% of \$1.70
6	90% of \$2.70, 10% of \$2.30	90% of \$3.40, 10% of \$1.70
7	15% of \$2.60, 85% of \$2.40	15% of \$3.30, 85% of \$1.80
8	30% of \$2.60, 70% of \$2.40	30% of \$3.30, 70% of \$1.80
9	45% of \$2.60, 55% of \$2.40	45% of \$3.30, 55% of \$1.80
10	60% of \$2.60, 40% of \$2.40	60% of \$3.30, 40% of \$1.80
11	75% of \$2.60, 25% of \$2.40	75% of \$3.30, 25% of \$1.80
12	90% of \$2.60, 10% of \$2.40	90% of \$3.30, 10% of \$1.80

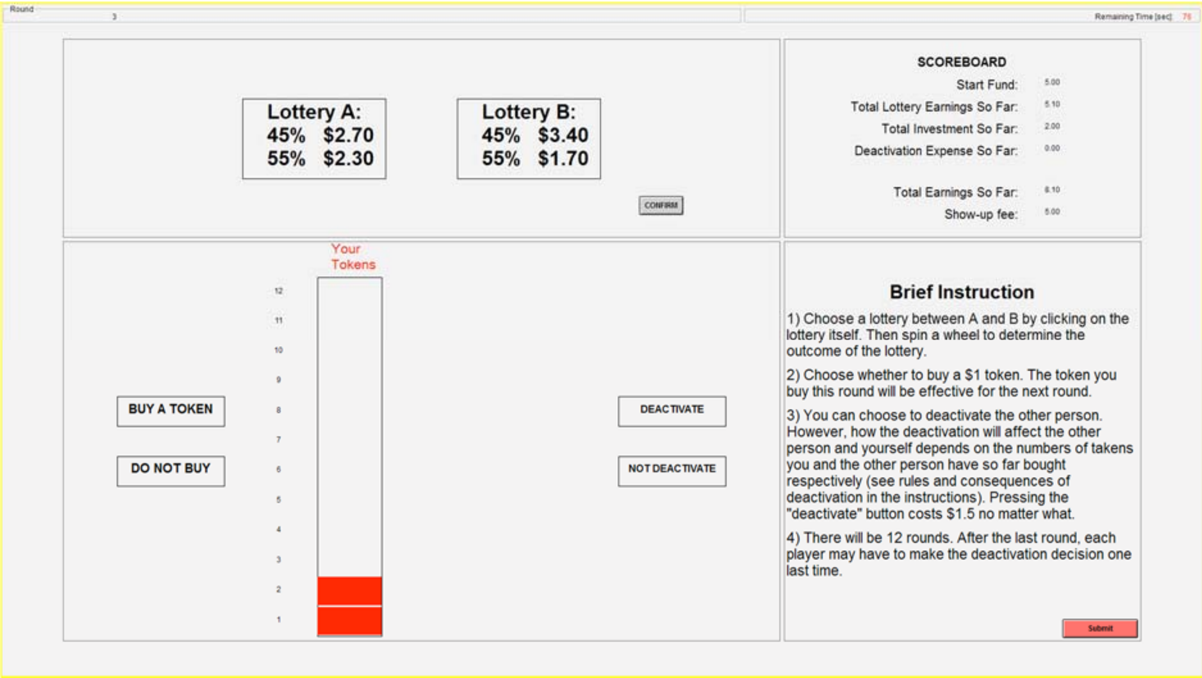
Choice if you have been deactivated

No.	Lottery A	Lottery B
1	15% of \$0.27, 85% of \$0.23	15% of \$0.34, 85% of \$0.17
2	30% of \$0.27, 70% of \$0.23	30% of \$0.34, 70% of \$0.17
3	45% of \$0.27, 55% of \$0.23	45% of \$0.34, 55% of \$0.17
4	60% of \$0.27, 40% of \$0.23	60% of \$0.34, 40% of \$0.17
5	75% of \$0.27, 25% of \$0.23	75% of \$0.34, 25% of \$0.17
6	90% of \$0.27, 10% of \$0.23	90% of \$0.34, 10% of \$0.17
7	15% of \$0.26, 85% of \$0.24	15% of \$0.33, 85% of \$0.18
8	30% of \$0.26, 70% of \$0.24	30% of \$0.33, 70% of \$0.18
9	45% of \$0.26, 55% of \$0.24	45% of \$0.33, 55% of \$0.18
10	60% of \$0.26, 40% of \$0.24	60% of \$0.33, 40% of \$0.18
11	75% of \$0.26, 25% of \$0.24	75% of \$0.33, 25% of \$0.18
12	90% of \$0.26, 10% of \$0.24	90% of \$0.33, 10% of \$0.18

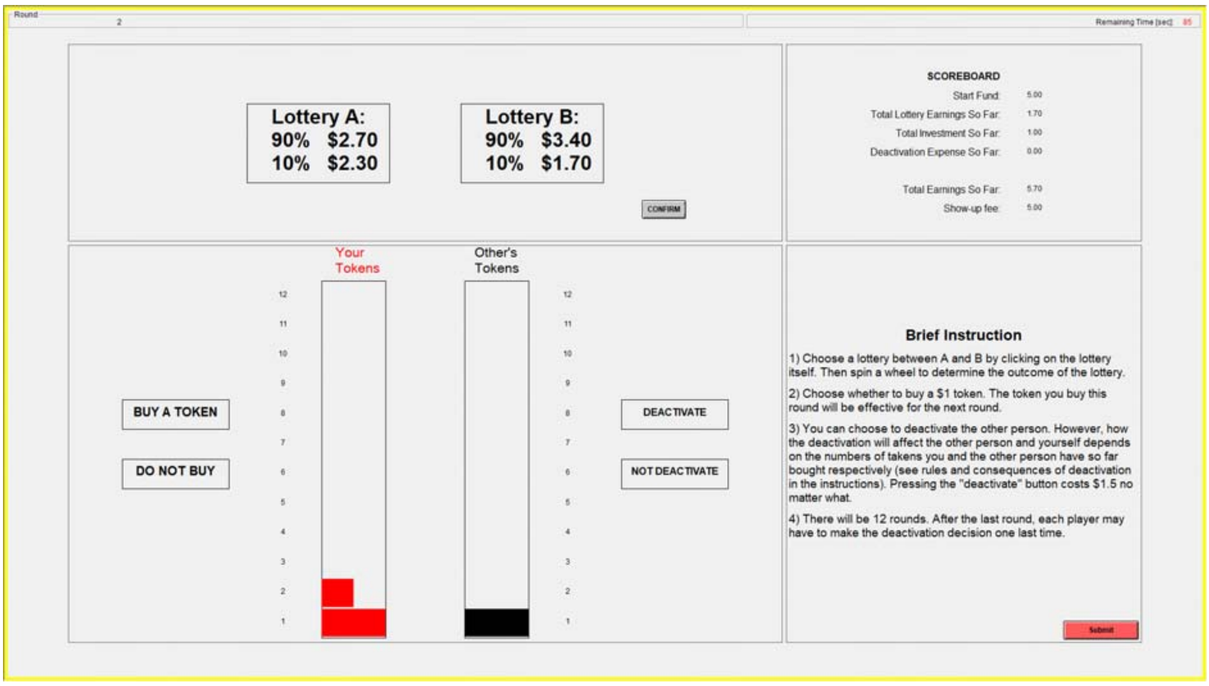
You make these 12 lottery choices in random order and you will not know the other person's earnings. If you have not been deactivated, then you choose lotteries from the left-hand side of the table. If you have been deactivated, then you choose the corresponding lotteries from the right-hand side of the table, where all payoffs are divided by 10. Likewise, if you deactivate the other person, then the other person from then on chooses lotteries from the right-hand side of the table, where all payoffs are divided by 10.

This completes the instruction. Before we begin the experiment, to make sure that every participant understands the instructions, please answer several review questions on your screen.

Screenshot for the Hidden Treatment



Screenshot for the Asymmetry Treatment



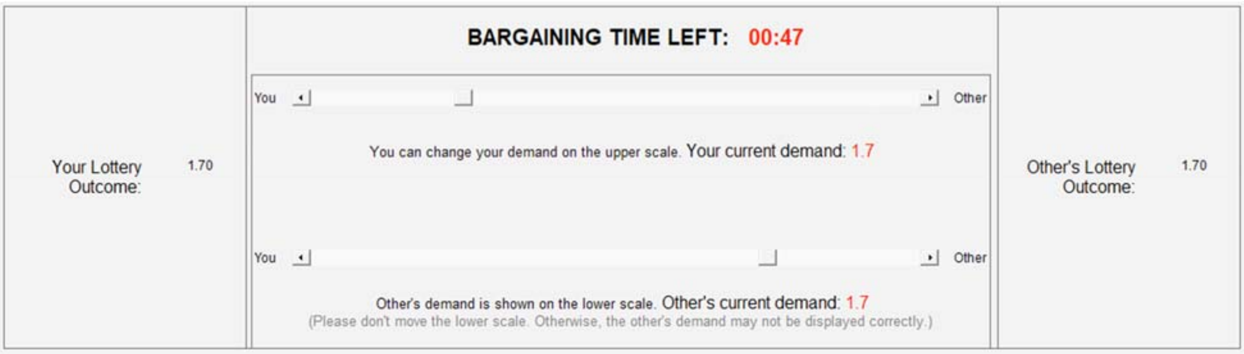
[Note: below we present the experimental instructions for the Trade treatment.]

Welcome to this experiment on decision-making. You have earned $5 for showing up on time. Please read the following instructions carefully. During the experiment, you will be asked to make a number of decisions. Your decisions and the decisions of other participants will determine your cash earnings. Your anonymity is ensured for the decisions you make. The experiment will consist of 12 rounds. No communication during the experiment is allowed. Final payment will be rounded to the nearest 10 cents. If you have a question, please raise your hand.

Matching: In each of the 12 rounds all participants will be matched in pairs. The pairs will be the same for all rounds. So you will be matched with another person and you will stay matched to this person throughout the whole experiment. You will NOT be rematched. In each pair, the computer will randomly select one person to be Person X and the other Person Y.

Lotteries: In each round, you can earn money by choosing between lotteries: you will see on your screen two lotteries displayed, lottery A and lottery B. You can choose either lottery A or B. After you made the choice, you can spin the wheel and the chosen lottery will be played out.

Bargaining: After both you and your pair have made the lottery decisions, you will be told both your and your pair's lottery earnings. Then, the pair will bargain over a fixed amount of money of $7 by clicking on a scale from $0 to $7 (see figure below). In 60 seconds, you can choose your demand on the upper scale and you can see your pair's demand in real time on the lower scale. On both scales, the amounts from the cursor to the left end represents your payoff and the amounts from the cursor to the right end represents your pair's payoff. (Please don't move the lower scale, which displays the other's current demand. It is not possible for you to change the other's demand by moving this scale.)



After the 60 seconds, if the sum of your and your pair's demands is no greater than $7 (i.e. a deal is made, see, e.g., figure A1), then each person's payoff equals to the amounts he/she demands in the bargaining. For example, in figure 2, in this round, you receive $3.4 and your pair receives $3.6. If the sum is greater than $7 (i.e. no deal is made, see, e.g., figure A2), then each person's payoff equals to his/her own lottery earnings. The payoff earned will be added to each person's total earnings.

Figure A1

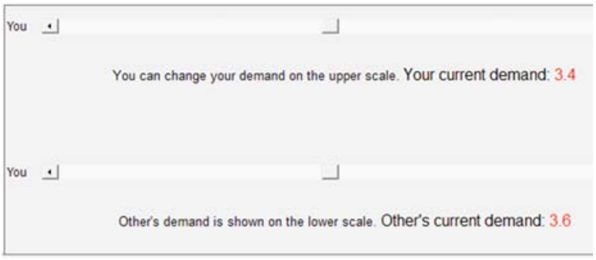
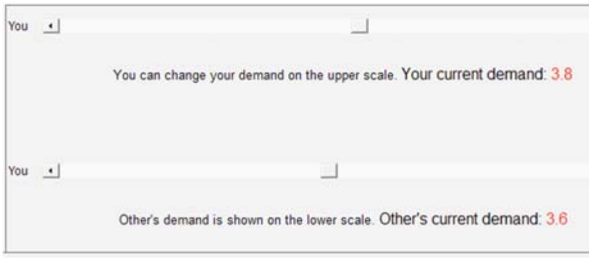


Figure A2



Tokens: Apart from the lottery decisions you have to make in each round, both you and the person you are matched with will have the option to invest $1 to buy a token *in each round*. That is, in each round, you will decide whether or not to buy a $1 token. Person X starts with 0.5 token and person Y starts with 0 token in round 1. The money spend in tokens is non-refundable and tokens are accumulated from round to round. Note that the token you have bought in one round will only be effective for the next round. For example, if you already have 2 tokens at the beginning of a round and decide to buy one more token in this round, it means you only have 2 tokens for this round, and you will have 3 tokens for the next round.

Deactivation: In each round, you will see your own and the other person's token balance, that is, the numbers of tokens bought up till this round. Both of you can decide whether to press the "deactivate" or "not deactivate" button. Pressing the "deactivate" button costs $1.5. You only have one chance to press the "deactivate" button.

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1. All earnings so far (including the start fund) for you will be set to $0.
2. All payoffs in the future lotteries for you will be divided by 10.
3. You will not be able to deactivate the other person in future rounds.

In summary, once a person is deactivated either directly by the other person or indirectly by his/her own action, it will wipe out his/her total earnings from all previous rounds and decrease the potential earnings from future rounds by 90%. Furthermore, a deactivated person will not be able to deactivate the other person.

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2) If no one has been deactivated after the last (12th) round, you will have the option to press the “deactivate” button one last time though there will be no lottery decision to make any more.

<u>The 12 lottery choices</u>

Choice if you have not been deactivated			Choice if you have been deactivated		
No.	Lottery A	Lottery B	No.	Lottery A	Lottery B
1	15% of \$2.70, 85% of \$2.30	15% of \$3.40, 85% of \$1.70	1	15% of \$0.27, 85% of \$0.23	15% of \$0.34, 85% of \$0.17
2	30% of \$2.70, 70% of \$2.30	30% of \$3.40, 70% of \$1.70	2	30% of \$0.27, 70% of \$0.23	30% of \$0.34, 70% of \$0.17
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You make these 12 lottery choices in random order and you will not know the other person’s earnings. If you have not been deactivated, then you choose lotteries from the left-hand side of the table. If you have been deactivated, then you choose the corresponding lotteries from the right-hand side of the table, where all payoffs are divided by 10. Likewise, if you deactivate the other person, then the other person from then on chooses lotteries from the right-hand side of the table, where all payoffs are divided by 10.

This completes the instruction. Before we begin the experiment, to make sure that every participant understands the instructions, please answer several review questions on your screen.

Appendix B. Additional Figures

[Note: this appendix shows additional figures. Figures B1-B4 show escalation in tokens and timing of deactivation per group per treatment, respectively. Whenever a "Deactivated" symbol falls upon a player's escalation path, it means that this player has been deactivated from that round onward. Figures B5-B6 depict bargaining processes for each active group in the first and last rounds of the Trade treatment. Most groups agree on equally splitting the bargaining pie at the end of the bargaining.]

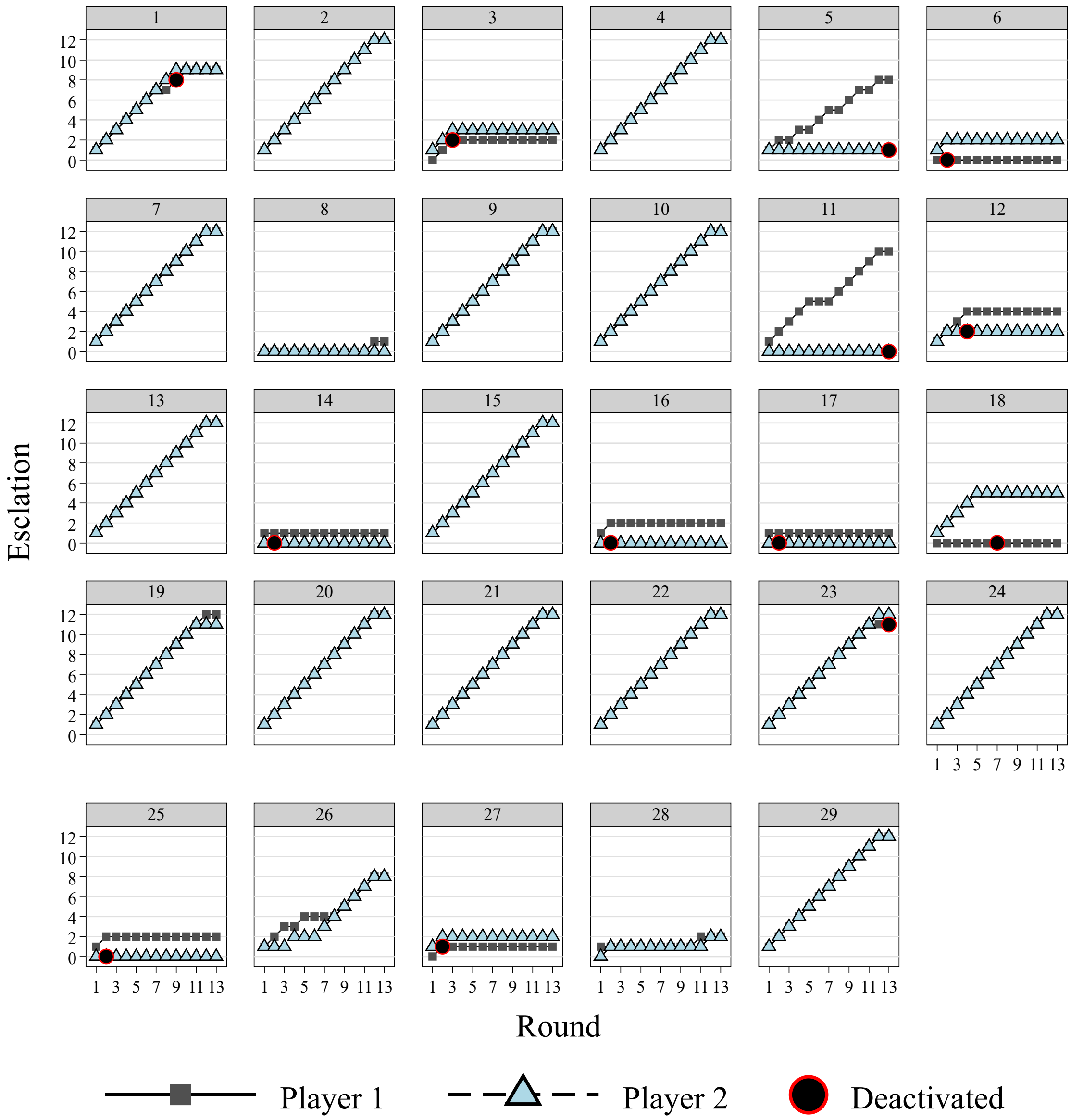

Figure B1: Group level results in the Base treatment

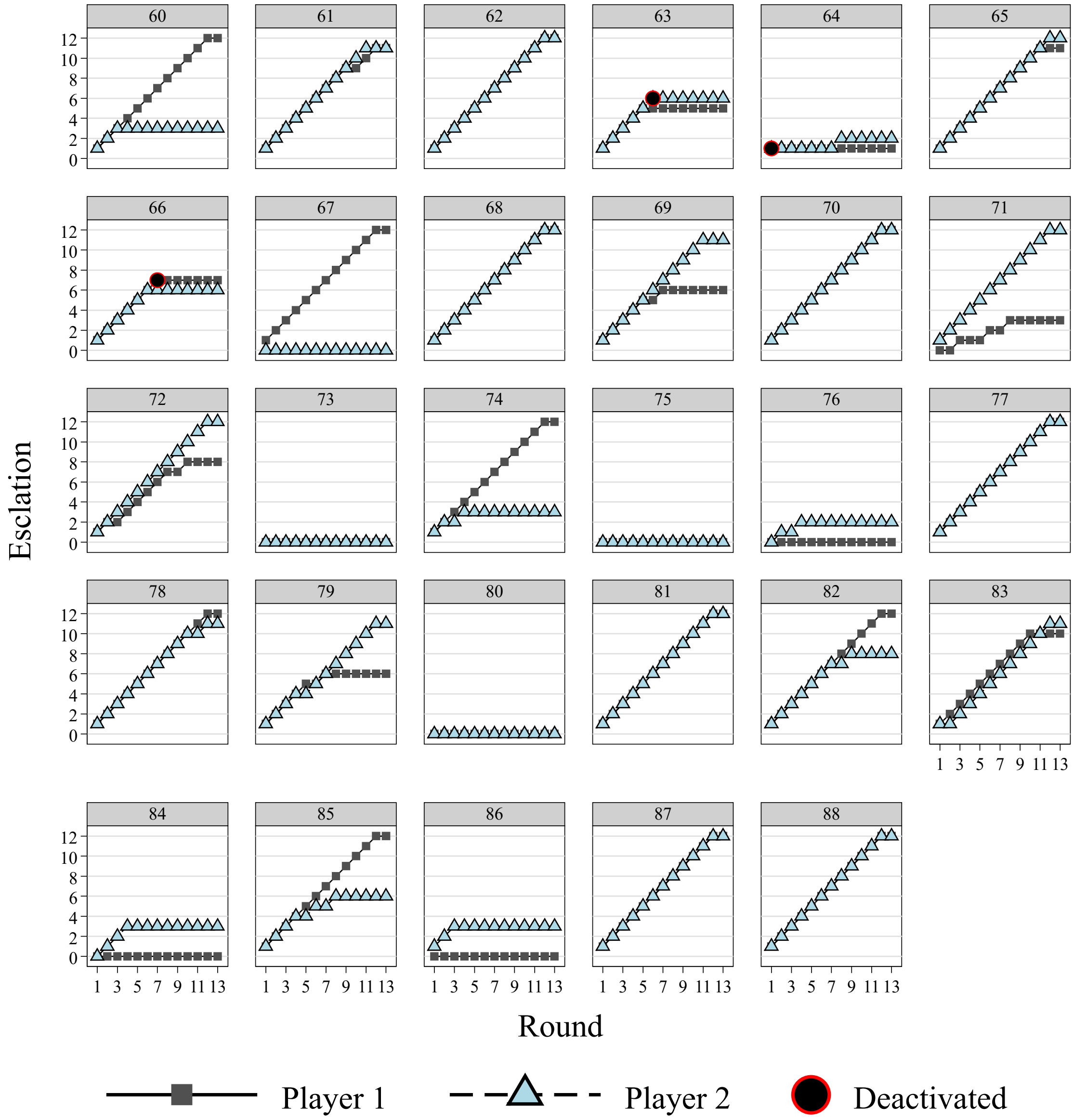

Figure B2: Group level results in the Hidden treatment

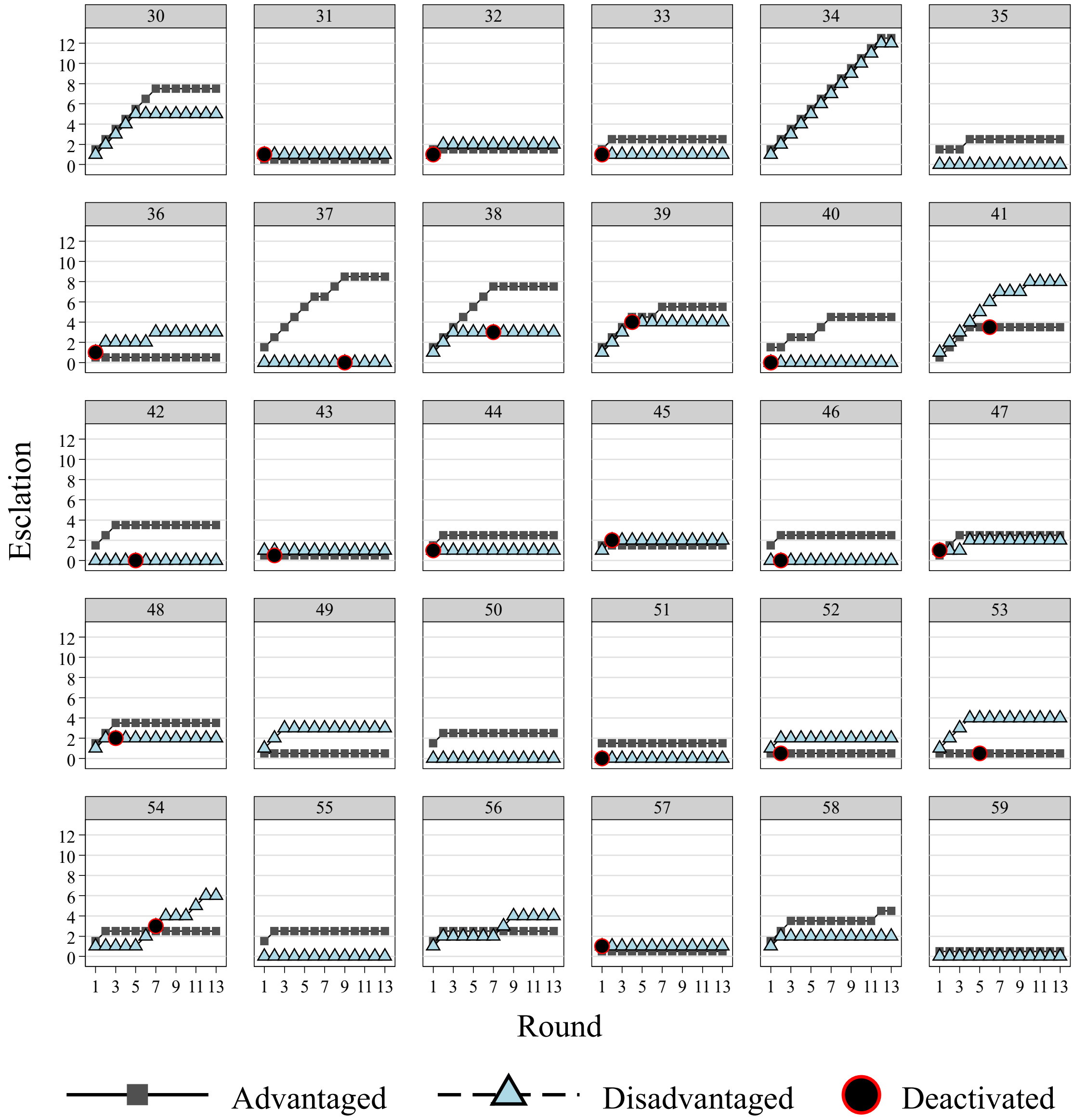

Figure B3: Group level results in the Asymmetry treatment

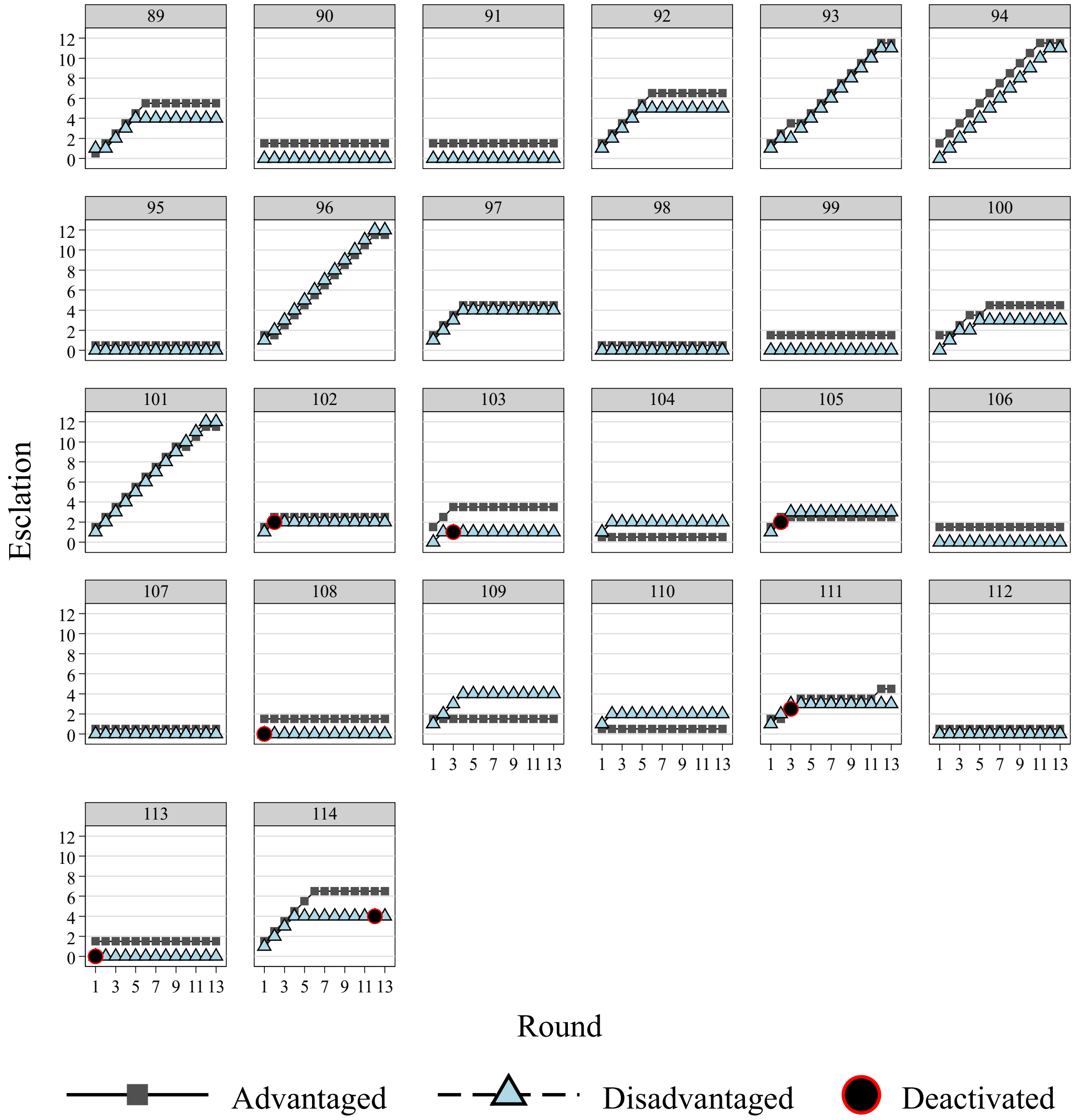

Figure B4: Group level results in the Trade treatment

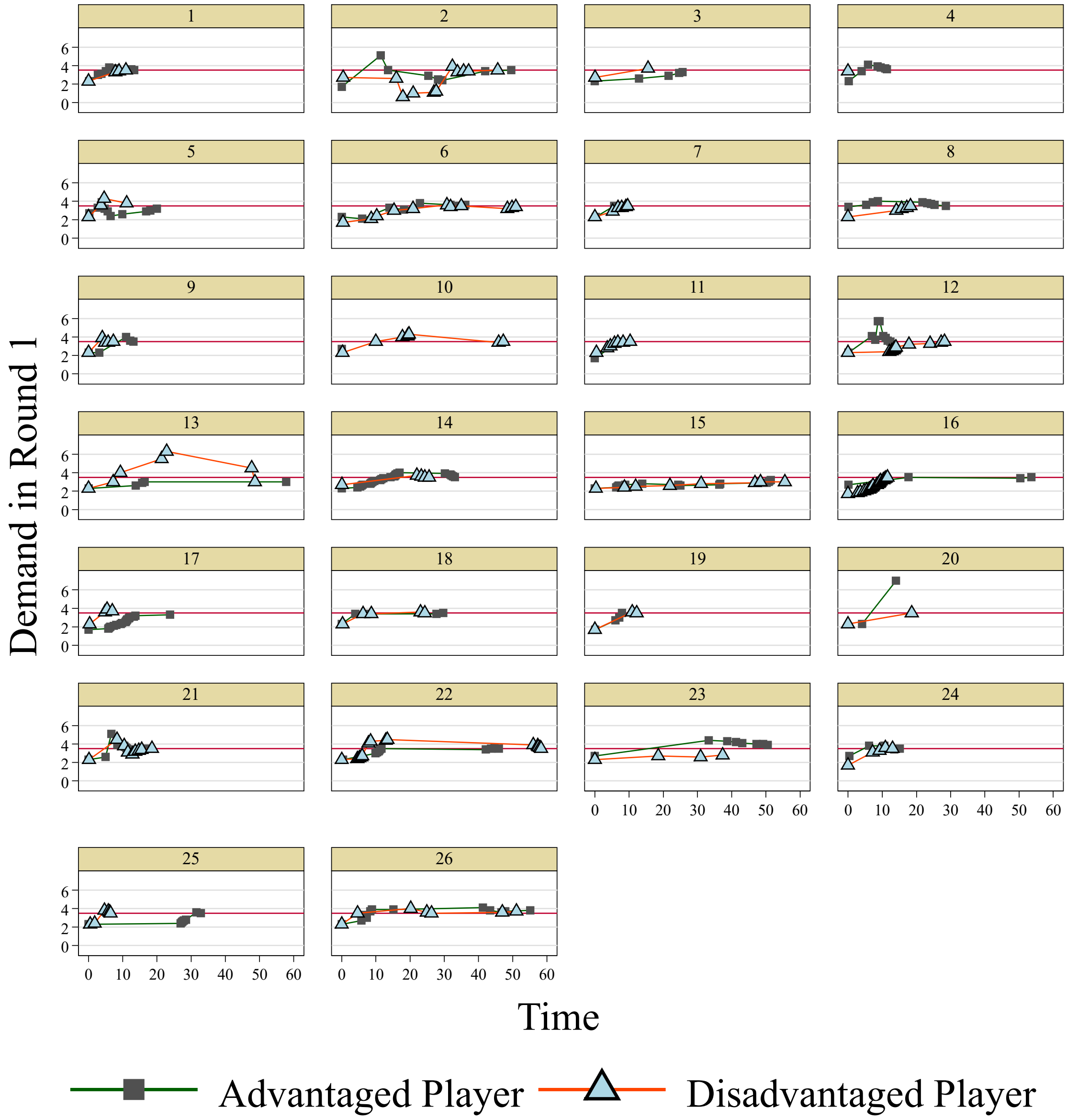

Figure B5: Group level bargaining demands over time in round 1

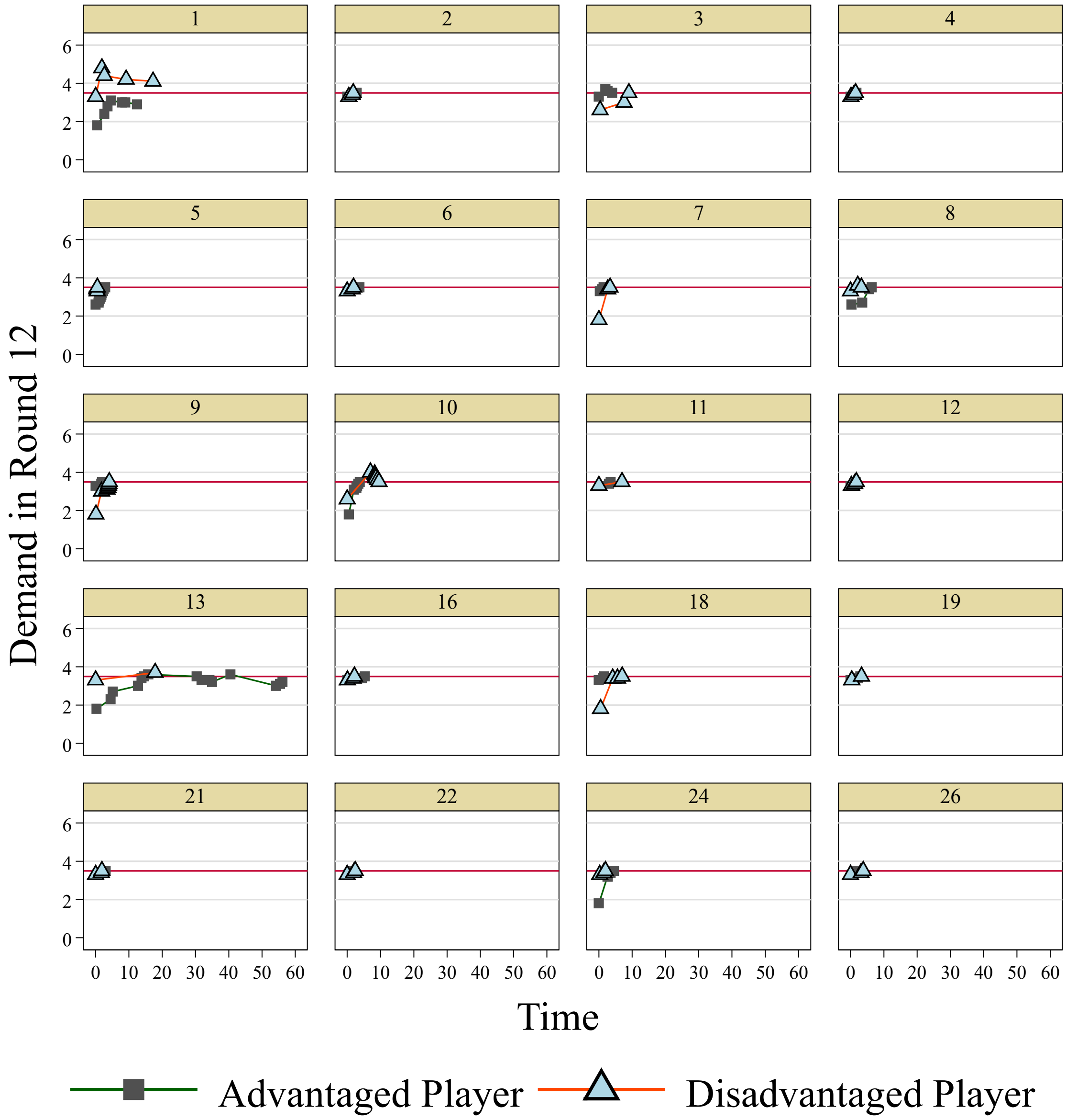

Figure B6: Group level bargaining demands over time in round 12

Appendix C. Proofs of Unique Subgame Perfect (or Sequential) Equilibrium

A.1. Subgame perfect equilibrium in the Base, Asymmetry and Trade treatments

Preliminaries. All games have two players denoted as player $i, j \in \{1,2\}$. All games have 13 rounds. In the first round, both players i simultaneously choose actions a_i^1 from choice sets $A_i(h^0) = \{R\&D; R\&ND; NR\&D; NR\&ND\}$ ($R = buy\ a\ rocket; NR = buy\ no\ rocket; D = deactivate; ND = don't\ deactivate$). (For clarity, we will ignore the lottery decisions, and the bargaining decisions in the Trade treatment, since they do not affect the equilibrium analysis as long as lottery and bargaining payoffs are treated as some exogenous endowment). At the end of the first round, both players observe the action profile $a^1 \equiv (a_1^1, a_2^1)$. At the beginning of the second round, players know history h^1, which can be identified with a^1. In our games, the actions player i has available in round 2, that is, the availability of the deactivation decision, depend on what has happened previously. Let $A_i(h^1)$ denote the set of possible actions when the history is h^1. In particular, if deactivation happened in the first round $A_i(h^1)$ shrinks to $\{R; NR\}$, and otherwise $A_i(h^1)$ remains the same as $A_i(h^0)$. Iteratively, we define h^k, the history at the end of round k, to be the sequence of actions in the previous rounds, $h^k = (a^1, a^2, \dots, a^k)$, and we let $A_i(h^k)$ denote player i's feasible actions in round $k+1$, for $k = 0, \dots, 12$. In particular, for $k = 12$, in the last round the only possible action available is the deactivation decision, that is, $A_i(h^{12}) = \{R; NR\}$ if deactivation has not occurred in previous rounds and otherwise $A_i(h^{12}) = \emptyset$.

A pure strategy for player i is a contingent plan of how to play in each round k for possible history h^{k-1}. Let H^{k-1} be the set of all round-(k-1) histories, and let $A_i(H^{k-1}) \equiv \bigcup_{h^{k-1} \in H^{k-1}} A_i(h^{k-1})$. A pure strategy for player i is a sequence of maps $\{s_i^k\}_{k=1}^{13}$, where each s_i^k maps H^{k-1} to the set of player i's feasible actions $A_i(H^{k-1})$, $s_i^k(h^{k-1}) \in A_i(h^{k-1})$ for all h^{k-1}. Since the terminal histories represent an entire sequence of play, we can represent each player i's payoff as a function $u_i: H^{13} \to \mathbb{R}$. With some abuse of notations, the payoff function at the terminal node is written as follows:

$$u_i = \begin{cases} \sum_{k=r+1}^{12}(0.1 * lottery\ payoff^k - 1_R^k) - 1.5 * \sum_{k=1}^{13} 1_D^k & if\ deactivated\ in\ round\ r \\ \sum_{k=1}^{12}(lottery\ payoff^k - 1_R^k) - 1.5 * \sum_{k=1}^{13} 1_D^k & if\ never\ deactivated \end{cases},$$

where 1_R^k is an indicator function of whether the player buys a rocket in round k; 1_D^k is an indicator function of whether the player presses the deactivate button in round k. Note that according to the rules of our games, a player will be deprived of this deactivation action as long as one of the two players has pressed the button in an earlier round, no matter which player has been deactivated. In that case, we also let $1_D^k = 0$ starting from the round when the deactivation decision becomes unavailable. Finally, $lottery\ payoff^k$ is a positive amount of money which may vary from round to round and always larger than \$1. (In the Trade treatment, on top of lottery payoffs, players may earn extra money from the bargaining. For simplicity, we only refer to $lottery\ payoff^k$.)

A subgame at the beginning of round k is defined as $G(h^{k-1})$. To define the payoff function in this subgame, let the final history be $h^{13} = (h^{k-1}, a^k, a^{k+1}, \dots, a^{13})$ and, therefore, the payoffs will be $u_i(h^{13})$. Strategies in $G(h^{k-1})$ are $\{s_i^k|h^{k-1}\}_{k=1}^{13}$, $s_i^r(h^{r-1}) \in A_i(h^{r-1})$ for all h^{r-1} consistent with h^{k-1}. Any strategy profile s of the whole game induces a strategy profile $s|h^{k-1}$ on any $G(h^{k-1})$ with the restriction of player i's strategy to be $s_i|h^{k-1}$.

Definition 1: A strategy profile s is a subgame perfect equilibrium if, for every h^k, $s_i|h^k$ is a Nash equilibrium of the subgame $G(h^k)$.

Proposition 1: There is a unique subgame perfect equilibrium in which neither player buys any rocket nor deactivate in any round in the Base, Asymmetry and Trade treatments.

Proof: With Definition 1, we can apply backward induction reasoning to find all subgame perfect equilibria. Note that players must pay \$1.5 to press the "deactivate" button, even if they deactivate themselves and their previous earnings from lotteries minus any rocket investment are set to 0. And the outcome of deactivation does not depend on who pressed the button but on the relative number of rockets. Thus, deactivation is a strictly dominated action in the last round. Let's replace the last-round strategies by the dominant strategies, $a^{13} = (a_1^{13}, a_2^{13}) = (ND, ND)$. (Off this path where deactivation happened in a previous round, there is no action to make.) In the penultimate round, each player's dominant strategy is again *ND* no matter which side has more rockets. Given a^{13}, buying a rocket is also a strictly dominated action since trying to gain an advantage in rocket number is meaningless for the last round. Thus, the penultimate-round strategies can be replaced by $a^{12} = (a_1^{12}, a_2^{12}) = (NR\&ND, NR\&ND)$. (Off this path where deactivation happened in a previous round, the Nash equilibrium for this subgame is (NR, NR).) Then consider the 11th round where a player may have incentive to deactivate in order to save on future expenses on rockets. To see that this incentive does not exist, note that a subgame at this round must be at one of the three situations: a player has more, equal or fewer rockets than the other player. However, in none of these situations does any player have incentive to deactivate as a preemption given that the penultimate-round optimal strategy profile specifies no deactivation. We consider one earlier round and apply the same reasoning, and so on, we find $a^1 = a^2 = \cdots = a^{12}$. Thus, the strategy profile based on the sequence of dominant strategies $\{a^k\}_{k=1}^{13}$ in each subgame constitutes a subgame perfect equilibrium. Since this is the only subgame perfect equilibrium found by backward induction, uniqueness follows. The above reasoning for finding the unique subgame perfect equilibrium holds equally well for the Base, Asymmetry and Trade treatments. Q.E.D.

A.2. Sequential equilibrium in the Hidden treatment

Defining sequential equilibrium requires a few more preliminary steps. A system of beliefs μ specifies beliefs at each information set h: $\mu(x)$ denotes the probability a player assigns to node x conditional on reaching information set $h(x)$. Specifically, since in the Hidden treatment the stock level of rocket is unknown to each other, a player's information set is different from histories defined in the complete information treatments. Let h_i^k denote player i's information set at round k. $h_i^k \equiv (a_i^k, y^k)$ where $y^k \equiv (y_1, y_2, \dots, y_k)$ and $\forall t < k, y_t \in$

$\{D, ND\}$. $y_t = D$ means that deactivation occurs in or before round t, and otherwise $y_t = ND$. $y_k = D$ iff $\exists t < k, \exists i \in \{1,2\}$ such that $a_i^t \in \{R\&D, NR\&D\}$.

Let $u_{i(h)}(s|h,\mu)$ be the expected payoff of player i at information set h with the player's beliefs given by $\mu(h)$ and strategies s. An assessment (s,μ) is *sequentially rational* if each player believes that the other player will adhere to the equilibrium strategy profile s at every information set whether reached or not reached in equilibrium. Formally, for any information set h and alternative strategy $s'_{i(h)}$,

$$u_{i(h)}(s|h,\mu) \geq u_{i(h)}((s'_{i(h)}, s_{-i(h)})|h,\mu).$$

To discipline beliefs at an information set off the equilibrium path, an assessment is consistent such that it is a limit point of some totally perturbed assessment (totally mixed strategies and associated beliefs pinned down by Bayes' rule). Formally, let Σ denote the set of all completely mixed strategies with profile σ such that $\sigma_i(a_i|h) > 0$ for all h and $a_i \in A(h)$. Let Ψ denote the set of all assessments (σ,μ) such that $\sigma \in \Sigma$ and μ is derived from σ by Bayes' rule. Players' beliefs are as if there were a small probability of a "tremble" at each information set with these trembles statistically independent of each other. As assessment (s,μ) is *consistent* if

$$(s,\mu) = \lim_{n\to\infty}(\sigma^n, \mu^n) \text{ for some sequence } (\sigma^n,\mu^n) \text{ in } \Psi.$$

Definition 2: A sequential equilibrium is an assessment (s,μ) that satisfies sequential rationality and consistency.

Proposition 2: There is a unique sequential equilibrium (in the sense of strategies but not necessarily the belief system) in which neither player buys any rocket nor deactivate in any round in the Hidden treatments.

Proof: First, we show that an assessment, in which no player buys any rockets or deactivates in any round and the players' belief system assigns probability 1 to this strategy in each round, is a sequential equilibrium. This assessment is sequentially rational since the deviation of a player to pressing the deactivate button in any round k cannot be profitable, given his belief that the other player will not deactivate in any round. As a result, any deviation to buying a rocket in some round also cannot be profitable. Consistency is also satisfied since the players' belief system μ simply corresponds to the pure strategy profile s in this essentially simultaneous move game within each round. This follows by using a sequence of mixed strategies σ^n in which each player plays the strategy of *NR&ND* in every round (and *ND* in the last round and *NR* if deactivation happened in a previous round) with probability $\frac{n-1}{n}$ and plays all other strategies with combined probability $\frac{1}{n}$, for each $n \in \mathbb{N}$, and a corresponding sequence of μ^n by Bayes rule.

Next, to show the uniqueness (in the sense of strategies but not necessarily the belief system), consider an assessment in which player i's strategy involves pressing the deactivate button in round k and player j's strategy involves pressing the button in round l, $l > k$. Player j would be notified of the consequence when player i pressed the deactivate button in round k and player j would actually not have the deactivation decision to make. Sequential rationality, nevertheless, requires a player's action to be optimal even at an information set not reached in equilibrium. Thus, player j's strategy which involves pressing the deactivate button in round l is not optimal (nor feasible): player j could have been better off by pressing the deactivate button before round k. Second, an assessment in which both players deactivate in the same round is not sequentially rational. A player could have saved the deactivation cost since his action would not affect the consequence of the other player's pressing the deactivate button. Third, any assessment in which only one player plans to deactivate in some round cannot be sequentially rational since this player faces no risk of being deactivated and thus has no incentive to deactivate the other player. Finally, any assessment in which no player presses the deactivate button but some player buys rocket(s) cannot be sequentially rational because rockets are essentially useless if no player has a plan to press the deactivate button. That leaves only the case where no player will deactivate or buy any rocket and hence the uniqueness holds. Q.E.D.