EXPERIMENTAL TESTS OF GLOBAL GAMES THEORY: COORDINATION, BARGAINING AND ENTRY GAMES

A Dissertation

by

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ABSTRACT

The theory of global games has shown that converting games with complete information to related games with incomplete information results in a unique equilibrium prediction that typically coincides with risk-dominance. This dissertation experimentally investigates this prediction in three different games: stag hunt, bargaining, and entry games. There are two treatments in each of these games, complete and incomplete information. In the stag hunt games, subjects under incomplete information conditions deviate significantly from the equilibrium prediction in favor of payoff dominance. They play similar strategies to those under complete information conditions. In the bargaining games most subjects conform to the risk-dominant prediction of global games theory, and convergence is stronger in games with incomplete information. In the entry games, in contrast to previous studies, subjects do not over-enter the market. This is because when too many people enter the market, firms' entry decisions become strategic substitutes, and subjects earn more by staying out of the market. There is less entry than the global games prediction. From these three games, I can conclude that subjects follow the comparative static predictions of global games theory, if not the precise predictions. Global games theory predictions are more powerful if there is no payoff dominance as an alternative prediction.

DEDICATION

To John Van Huyck (1956-2014); my parents, Prasong and Chuenpan Viriyavipart; my brother, Keerajak Viriyavipart (1986-2010); and my sister, Pitchayan Viriyavipart.

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1. INTRODUCTION: GLOBAL GAMES AS AN EQUILIBRIUM SELECTION TOOL

Multiple strict equilibria arise in many economic situations: for example, team production, public good provision, currency attacks, bank runs, market entry, and technology adoption, see Cooper (1999). The refinements literature attempts to solve this indeterminacy by imposing additional rationality restrictions or by requiring additional robustness properties to refine the Nash equilibrium concept. However, because the equilibria are strict they survive all of the usual refinements, see Van Damme (1991).

In an innovative paper, Carlsson and van Damme (1993b) demonstrate that converting a complete information game with multiple strict equilibria into an incomplete information game, called a global game, results, in many cases, in a unique dominance solvable equilibrium prediction. The conversion is motivated by the observation that even in complete information games, where the game form is common knowledge, players are uncertain about others' utility from the game. Usually, the theory of global games assumes a special case of this general problem in which the incomplete information game arises from players each observing a noisy signal of a common state variable.

Morris and Shin (2001) motivate the importance of global games analysis by observing that it is a "...heuristic device that allows the economist to identify the actual *outcomes* in such games, and thereby open up the possibility of systematic analysis of economic questions which may otherwise appear to be intractable." Multiple equilibra are the consequence of two modeling assumptions: First, the economic fundamentals are assumed to be common knowledge; second, players are assumed to

Table 1.1: A Class of Stag Hunt Games

	A	B
A	$1, 1$	$0, q$
B	$q, 0$	q, q

be certain about others' behavior in equilibrium, see also Morris and Shin (2000). They write, "...global games allow modelers to pin down which set of self-fulfilling beliefs will prevail in equilibrium."

(Carlsson and van Damme, 1993b, p.1012) do not rely only on common knowledge of rationality to justify the global games' predictions. They argue that for a great variety of learning processes the sequence of choices will eventually converge to the set of strategies that survive iterated elimination of strictly dominated strategies, see Milgrom and Roberts (1991). This suggests that the global games approach may also be interpreted as the stochastic steady state of a realistic learning process.

In this dissertation, I test the predictions of the global games theory in laboratory experiments in three different games: stag hunt, bargaining and entry games. In all of these three games, there exists a unique Nash equilibrium in games with incomplete information, in which players only observe some payoffs with noise; however, there are multiple Nash equilibria in games with complete information. I summarize these three games in this chapter. Chapters 2, 3 and 4 discuss in more detail about stag hunt, bargaining and entry games, respectively. Chapter 5 concludes the dissertation.

1.1 Global Stag Hunt Games

The class of stag hunt game forms, depicted in table 1.1, models a situation in which symmetric players have two choices: a risky choice (A) and a safe choice (B). Choice B guarantees a payoff of q while choice A yields a high payoff of 1 if the other player also chooses A, but yields a low payoff of 0 if the other player chooses B. If

Table 1.2: A Class of Global Stag Hunt Games Observed by Player i

	A	B
A	$1, 1$	$0, q + \epsilon_i$
B	$q + \epsilon_i, 0$	$q + \epsilon_i, q + \epsilon_i$

$q \in [0, 1]$, the game has two strict equilibria: either both players choose A or both players choose B. The equilibria are Pareto ranked, and (A, A), a payoff-dominant equilibrium, dominates (B, B), a secure equilibrium. While this favors A, strategic uncertainty, which is inherent in the strategy coordination problem, may lead players to choose B instead. Intuitively, if q is high, then it is more likely that players will choose B.

Harsanyi and Selten (1988) develop risk dominance as the selection principle when payoff dominance fails to make a unique prediction. For a 2×2 game, risk dominance is equivalent to choosing the equilibrium with the larger basin of attraction under best response dynamics. It is straightforward to show that the (A, A) equilibrium has the larger basin of attraction when $q < 0.5$ in which case both payoff dominance and risk dominance agree on the selection of all A. However, when $q > 0.5$ the (B, B) equilibrium has the larger basin of attraction in which case payoff dominance and risk dominance conflict.

Carlsson and van Damme (1993b) develop an equilibrium selection theory based on the idea that the payoff parameters of a game cannot be observed with certainty. The complete information stag hunt game in table 1.1 is replaced by a payoff perturbed game: a global stag hunt game. In this game, each player observes the payoff table in table 1.2 but his/her payoff is determined by the actual table in table 1.1.

Following (Carlsson and van Damme, 1993a, Section 4), we assume that everything about the stag hunt game is common knowledge except the payoff to the safe choice q. Each player receives a signal $q_i = q + \epsilon_i$ that provides an unbiased estimate of q. The signals are noisy so q is not common knowledge amongst the players. Let q denote a random variable that is distributed on the interval $[a.b]$ where $a < 0$ and $b > 1$. So it is possible that $q > 1$ in which case B strictly dominates A and it is possible that $q < 0$ in which case A strictly dominates B. Let (ϵ_1, ϵ_2) denote a two-tuple of zero mean independently and identically distributed random variables. The ϵ_i are assumed to be independent of q and to be distributed within $[-E, E]$ where $E < -\frac{a}{2}$ and $E < \frac{b-1}{2}$. The incomplete information model is described by the following rules:

1. $(q, \epsilon_1, \epsilon_2)$ are randomly generated to obtain (q, q_1, q_2).
2. Player i observes q_i and chooses between A and B.
3. Each player i receives payoffs which determined by choices made in step 2 and the actual value of q in the table 1.1 with the mean matching protocol.

Because each player observes a different estimated value of q, the only strategy that can be a best response is a threshold strategy. Carlsson and van Damme (1993b) show that there exists only one threshold, [1] q^*, that survives iterated elimination of strictly dominated strategies in the Global Stag Hunt Game.In this game, a unique threshold, $q^* = 0.5$. Remarkably this is true for any $\varepsilon > 0$ that are arbitrary small (smaller than $-\frac{a}{2}$ and $\frac{b-1}{2}$). Carlsson and van Damme's argument thus gives another reason to expect the risk-dominant equilibrium if the players have arbitrarily small uncertainty about q. In the Global Stag Hunt Game, using a threshold of 0.5 is the unique dominance solvable equilibrium.

Table 1.3: A Class of Bargaining Games

	A	B
A	W, X	100, 100
B	100, 100	Y, Z

1.2 Global Bargaining Games

In a bargaining game shown in table 1.3, there are two strict equilibria in pure strategies: (A, A) and (B, B). Many equilibrium selection principles have been proposed to select an equilibrium when there are multiple equilibria. One of the principles that has been widely used is payoff dominance. It compares the efficiency of equilibria and selects the equilibrium that all players earn the most. In this game, because the row player earns more with (A, A) while the column player earns more with (B, B); there is no payoff-dominant equilibrium.

Harsanyi and Selten (1988) develop risk dominance as the selection theory when payoff dominance fails to make a unique prediction. In 2×2 games, risk dominance is equivalent to choosing the equilibrium with the larger basin of attraction under best-response dynamics. In other words, it selects the equilibrium with the larger product of the deviation losses. In this game, risk dominance selects (A, A) when $(W-100)\times(X-100) > (Y-100)\times(Z-100)$ and (B, B) when $(W-100)\times(X-100) < (Y-100) \times (Z-100)$.

There are at least two other equilibrium selection principles that have been widely used in bargaining: Rawlsian and Utilitarian. Rawlsian (Rawls (1971)) selects the equilibrium that maximizes the payoff of the worst off player; it selects (B, B) in this game because Y and Z are both greater than X. Utilitarian selects the equilibrium with the largest payoff sum; it selects (A, A) when $W+X > Y+Z$ and (B, B) when

[1] A threshold q^* refers to a strategy in which a player chooses A if $q_j < q^*$ and B if $q_j > q^*$

Table 1.4: A Class of Global Bargaining Games (a, left) Actual Payoff Table; (b, right) Subject i's Estimated Payoff Table.

	A	B
A	W, X	100, 100
B	100, 100	Y, Z

	A	B
A	W_i, X_i	100, 100
B	100, 100	Y_i, Z_i

$W + X < Y + Z$.

Carlsson and van Damme (1993b) develop an equilibrium selection theory (a global game) based on the idea that the payoff parameters of a game cannot be observed with certainty. The complete information bargaining game in table 1.3 is replaced by a payoff perturbed game: a global bargaining game, as in table 1.4. The global game can be described by the following steps:

1. Nature selects W, X, Y, Z.
2. Each player independently observes W, X, Y, Z with some noise, so we denote them as W_i, X_i, Y_i, Z_i for subject i.
3. Each player chooses between A and B simultaneously.
4. Each player receives payoffs as determined by the game form in step 1 and all players' choices in step 3.

In other words, player i observes a game on table 1.4b but the payoffs are determined by a game on table 1.4a. Carlsson and van Damme (1993b) show that for any 2×2 game, under some restrictions, iterated elimination of dominated strategies in the global game forces each player to select an equilibrium equivalent to the risk dominance criteria. The restrictions are (1) the initial subclass of games is large enough and contains games with different equilibrium structures and (2) the noise is

Table 1.5: A Class of Entry Games where $Q \in [0, 400]$

No. of choice A	0	1	2	3	4	5	6
A	Q	$Q + 50$	$Q + 100$	$Q + 200$	$Q + 100$	$Q + 50$	Q
B	300	300	300	300	300	300	300

independently distributed and is sufficiently small.[2]

Under incomplete information (i.e., global bargaining games), there exists a unique equilibrium that is the same as the equilibrium derived from the risk dominance criterion. Other equilibrium selection principles including Rawlsian and Utilitarian are no longer equilibria because observing different parameters can lead to different choices.

1.3 Global Entry Games with Strategic Substitutes and Complements

The class of entry game with strategic substitutes and complements, depicted in Table 1.5, models a situation in which symmetric players have two choices: A, enter the market, and B, do not enter the market. Choosing B and staying out of the market guarantees a payoff of 300 regardless of other players' choices. If a person chooses A and enters the market, the payoff depends on Q and the number of other players who choose to enter the market. The payoff is highest when 3 other players also choose A; the payoff is lower as the number of other players who choose A is further away from 3.

Under complete information, there is a unique dominance solvable equilibrium when Q is less than 100 where all players play B; and when Q is more than 300 where all players play A. Multiple equilibria exist when $Q \in (100, 300)$. Two symmetric equilibria are the following: (1) All players choose B; (2) Each player plays a mixed strategy in which all players have the same probability of choosing A for the same

[2] See Carlsson and van Damme (1993b) for details of the proof.

Table 1.6: A Class of Global Entry Games where $Q \in [0, 400]$, $Q_i = Q + E_i$ where $E_i \in \{-120, -119, ..., 0, ..., 120\}$

No. of choice A	0	1	2	3	4	5	6
A	Q_i	$Q_i + 50$	$Q_i + 100$	$Q_i + 200$	$Q_i + 100$	$Q_i + 50$	Q_i
B	300	300	300	300	300	300	300

value of Q. There are also many asymmetric equilibria.

In the game with incomplete information, the fundamental state variable (Q) cannot be observed with certainty. Each player observes the incomplete information in Table 1.6 but the actual payoffs are determined by the game in Table 1.5. In contrast to the game with complete information conditions, there exists a unique threshold equilibrium in which players choose A and enter the market as long as $Q_i \geq 182$ and choose B and stay out of the market when $Q < 182$ in game with incomplete information conditions.

1.4 Global Games Experiments

There are different predictions between complete and incomplete information, i.e., multiple equilibria in games with complete information and a unique equilibrium in games with incomplete information. Therefore, I experimentally test the predictions under both complete and incomplete information in all three games. The experimental results are used to: (1) compare the results of the game with complete information to those with incomplete information; and (2) test if the subjects conform to the global games predictions.

The results from the global stag hunt games show that subjects under complete information play similar strategies to those under incomplete information. Under complete information, subjects coordinate on the payoff maximizing equilibrium, as expected. Under incomplete information, subjects exhibit substantial deviations from the equilibrium prediction of global games, coordinating just as well as subjects in the complete information treatment.

In contrast to the results from the global stag hunt games, the majority of subjects in the global bargaining games conform to the global games theory. When using a finite mixture model, two-third of the subjects under incomplete information and about half of the subjects under complete information can be classified as the risk dominance (or global games) type. The results support the global games theory as risk dominance is more salient under incomplete information. It also suggests that players may use different strategies in games with different information conditions. The implied "social preferences" of people are different under different information conditions. Incomplete information can change people with different strategies to use similar strategies in bargaining games.

The results from the global entry games with strategic substitutes and complements are in contrast to previous literature about global entry games with strategic complements only: subjects in my experiments do not enter the market more often than theoretical predictions as subjects in previous studies do. In fact, they enter the market less often, i.e., use thresholds lower than the theoretical prediction. The results indicate that subjects do not over-select risky options in the absence of payoff dominance.

2. WHEN LESS INFORMATION IS GOOD ENOUGH: EXPERIMENTS WITH GLOBAL STAG HUNY GAMES

2.1 Introduction

Previous experimental work has shown that when playing a sequence of stag hunt games, each having multiple equilibria, most subjects can coordinate on the Pareto superior equilibrium, see Rankin, Van Huyck and Battalio (2000). This result, however, was documented in an environment with complete information, i.e., where subjects knew all individuals' exact payoffs. Ideally, such coordination would persist in environments with incomplete information as well since knowing payoffs with precision may not always be possible. According to the theory of global games of Carlsson and van Damme (1993b), adding even a very small amount of noise to the payoffs–which transforms the game into one of incomplete information–yields a unique equilibrium that is less efficient than what is found in lab experiments with complete information.. Despite this unfavorable theoretical prediction, departures from equilibrium behavior have been widely documented in the lab and the field. As a result, it is unclear whether having incomplete information would significantly reduce social welfare in practice.

In this chapter, I conduct an experiment where each subject plays a sequence of perturbed stag hunt games in one of two treatments: one with complete and one with incomplete information. Under complete information, subjects coordinate on the payoff maximizing equilibrium, as expected. Under incomplete information, subjects exhibit substantial deviations from the equilibrium prediction of global games, coordinating just as well as subjects in the complete information treatment. Thus the efficiency loss from observing imprecise information is not as drastic as theory

Table 2.1: A Class of Stag Hunt Games

	A	B
A	$1, 1$	$0, q$
B	$q, 0$	q, q

would suggest.

The class of stag hunt game forms depicted in Table 2.1 models a situation in which symmetric players have two choices: a risky choice (A) and a safe choice (B). Choice B guarantees a payoff of q while choice A yields a high payoff of 1 if the other player also chooses A, but yields a low payoff of 0 if the other player chooses B. If $q \in [0, 1]$., the game has two strict equilibria: either both players choose A or both players choose B. The equilibria are Pareto ranked in which (A, A), a payoff-dominant equilibrium, dominates (B, B), a secure equilibrium. While this favors A, strategic uncertainty, which is inherent in the strategy coordination problem, may lead players to choose B instead. Intuitively, if q is high, then it is more likely that players will choose B. In fact, risk dominance (Harsanyi and Selten (1988)) selects (A, A) when $q < 0.5$ and (B, B) when $q > 0.5$.

Given the fact that it is more attractive to choose B when q is high, I expect players to play "threshold" strategies where the players choose A if $q \leq q^*$ and B if $q > q^*$ for some $q^* \in [0, 1]$. Any strategy profile where both players use threshold strategies with the same q^* will constitute an equilibrium because players will always end up playing (A, A) when $q \leq q^*$ and (B, B) when $q > q^*$.

Previous experimental research demonstrates the selection of the high-payoff equilibrium is reached even when the structure of the game is changed in each period. However, this game assumes that subjects know the payoff structure with extreme precision, (i.e., complete information). This assumption may not be realistic as subjects may not be able to observe, or it may be too costly to observe precise information. Therefore, I introduce noise to the value of q as in global games by Carlsson and van Damme (1993b). In this global stag hunt game, each player independently observes the value of q with noise in each period. Payoff dominance is no longer an equilibrium because even when players use the same threshold, observing different estimated values of q can lead them to select different choices. The theory of global games has shown that the only equilibrium in this game is the risk-dominant threshold ($q^* = 0.5$) and iterated elimination of dominated strategies forces the players to conform to this unique dominance solvable equilibrium.

The unique equilibrium prediction from global stag hunt games has lower expected payoffs than the payoff dominance observed in previous studies. However, it has been shown in many settings that people may deviate from the equilibrium, especially when playing the equilibrium yields low payoffs.[1] Therefore, it is unclear whether having less precise information would significantly reduce the social welfare as the theory suggests.

Given the uncertainty about behavior, I compare a sequence of perturbed stag-hunt games in two treatments: complete information and incomplete information. Under complete information treatment, subjects observe the actual value of q with certainty, while under incomplete information treatment, subjects observe the value of q with noise that is uniformly distributed with zero mean.

Our results show that under complete information, most subjects use threshold strategies that are close to the payoff-dominant equilibrium as expected.[2] Under incomplete information, subjects deviate significantly from the theory; only two out of

[1] Prisoners' dilemma is a good example , see Rapoport and Chammah (1965) for many experimental results.

[2] There is one remarkable cohort in which all eight subjects use the payoff-dominant threshold in the last 50 periods.

nine cohorts use the thresholds that are closer to the theoretical equilibrium threshold than the payoff-dominant threshold. All other cohorts use thresholds that are close to the payoff-dominant threshold: their behavior is similar to subjects in the complete information treatment. The efficiency loss from observing imprecise information is substantially smaller than the theoretical prediction.

To my knowledge, this paper is the first to examine the predictions of global games theory in the stag hunt game. It is also first to compare the results of the game with complete information to those with incomplete information. The closest paper to mine, Rankin, Van Huyck and Battalio (2000), only examine the game under complete information; my design in the complete information treatment is intentionally similar to theirs.[3] That paper reports an experiment in which subjects play a sequence of 75 perturbed stag hunt games under complete information where payoffs, action labels, and game forms are changed in each period. They show that payoff dominance emerges as an equilibrium selection principle. In the last 15 periods, most subjects use threshold strategies that are close to 1, a payoff-dominant threshold, and more than half of the subjects select a risky choice even when the value of q is as large as 0.97.

In summary, this paper considers a sequence of perturbed stag-hunt games in two treatments: complete information and incomplete information. Although under incomplete information treatment, the theory predicts subjects will coordinate on

[3]Our design is different from Rankin, Van Huyck and Battalio (2000) in three important ways. First, subjects are matched against everyone in the cohort each period and receive a payoff equal to the mean of the matches. Stahl and Van Huyck (2002) call this protocol mean matching. Getting feedback from everyone in the cohort aids the speed of adjustment and reduces the high variance within cohort. Second, q is allowed to be smaller than 0 and larger than 1 as required by the global games theory to get a unique equilibrium. In order to apply iterated dominance argument, it requires the initial subclass of games to be large enough and contains games with different equilibrium structures. Lastly, actions labels are fixed (a risky choice is always labeled A and a safe choice is always labeled B) and subjects play the games for 100 periods. After each period, each subject receives feedback on the the actual value of q, number of subjects in the cohort who chose A and B, and his/her payoff.

the risk-dominant threshold; subjects deviate significantly from that threshold toward payoff-dominant threshold. We find no significant difference between subjects' earnings in two treatments which suggests that the efficiency loss from not observing precise information may not be as high as the theory predicts.

2.2 Analytical Framework

To study whether subjects can coordinate with imprecise information, I intentionally choose a stag hunt game because of the its different prediction under complete and incomplete information. Under complete information, any strategy profile where both players use the same threshold strategy will constitute an equilibrium. However, under incomplete information, iterated elimination of dominated strategies forces the players to conform to the unique threshold equilibrium which is not efficient. Given this theoretical prediction, it is unfavorable for subjects in incomplete information to coodinate.

To focus the analysis, consider complete information stag hunt game forms where n identical players, indexed by i, simultaneously choose between A and B. Let k denote the number of players, including i, that choose A. Each player i is matched with the other $n-1$ players and earns the average payoff, from these matches using Table 2.1. This is the matching protocol used in the experiment, which is called a mean matching protocol. Player i's payoff to A is $p(k,n) = \frac{k-1}{n-1} \cdot 1 + \left(1 - \frac{k-1}{n-1}\right) \cdot 0 = \frac{k-1}{n-1}$ for $k \geq 1$[4] and to B is q.

Suppose $q \in (0,1)$, consider the strategy assignment in which all n players choose A. Since $k = n$, the payoff to A is 1. Deviating from the strategy assignment yields q, which is less than 1 by assumption. Hence, playing A is a best response to the

[4] Since k cannot be less than 1 when player i chooses A, define $p\,(k,n) \equiv 0$ for $k < 1$. Notice that $p(x)$ is non-decreasing with $p(0) = 0$ and $p(1) = 1$ as required by (Carlsson and van Damme, 1993a, p.239).

other $n-1$ players choosing A and by symmetry a strict Nash equilibrium. Consider the strategy assignment in which all n players choose B. The payoff to B is always q. Deviating from the strategy assignment yields 0, which is less than q by assumption. Hence, playing B is a best response to the other $n-1$ players choosing B and by symmetry a strict Nash equilibrium.[5]

All of the players prefer all A, which yields them 1, over all B, which yields them less than 1. The presence of multiple Pareto ranked equilibria confronts the player with a strategy coordination problem. While this favors A, strategic uncertainty, which is inherent in the strategy coordination problem, may lead players to choose B instead. Intuitively, if q is high, then it is more likely that players will choose B.

2.2.1 Equilibrium Selection

Harsanyi and Selten (1988) struggle with the choice of selection theory and ultimately give priority to payoff dominance, which compares the efficiency of equilibria and, if it exists, selects the equilibrium that all players prefer. In the class of stag hunt games under consideration this principle selects the all A equilibrium regardless of the value of q, which does not capture the intuitive notion discussed in the introduction that the likelihood of all A should depend on q.[6]

Given the fact that it is more attractive to choose B when q is high, I expect a rational player to play a "threshold" strategy where the player chooses A if $q \leq q^*$ and B if $q > q^*$ for some $q^* \in [0,1]$. Any strategy profile where all players use threshold strategies with the same q^* will constitute an equilibrium because the group will always end up playing all A when $q \leq q^*$ and all B when $q > q^*$. The payoff dominance has a threshold of 1 because it suggests subject to select A when

[5]There are no other strict Nash equilibria, see (Carlsson and van Damme, 1993a, Proposition 2.1).

[6]In the global stag games to be introduced below, A is not always the payoff-dominant equilibrium anymore since q can be larger than 1; in which case, B strictly dominates A.

Table 2.2: A Class of Global Stag Hunt Games Observed by Player i

	A	B
A	$1, 1$	$0, q + \epsilon_i$
B	$q + \epsilon_i, 0$	$q + \epsilon_i, q + \epsilon_i$

$q \leq 1$.

Harsanyi and Selten (1988) develop risk dominance as the selection principle when payoff dominance fails to make a unique prediction. For $n = 2$, risk dominance is equivalent to choosing the equilibrium with the larger basin of attraction under best response dynamics. It is straightforward to show that the (A, A) equilibrium has the larger basin of attraction when $q < 0.5$ in which case both payoff dominance and risk dominance agree on the selection of all A. However, when $q > 0.5$ the (B, B) equilibrium has the larger basin of attraction in which case payoff dominance and risk dominance conflict.

For $n > 2$, (Harsanyi and Selten, 1988, p.207-209) use the tracing procedure to select the risk-dominant equilibrium. It is straightforward to check the conditions given in Proposition 3.1 of Carlsson and van Damme (1993a) to find the critical value of q, denoted q^*, that determines if risk dominance and payoff dominance conflict: $q^* = 0.5$ as in the case where $n = 2$. Risk dominance selects all A when $q < 0.5$ and all B when $q > 0.5$, a threshold of 0.5.

2.2.2 Global Stag Hunt Games

Carlsson and van Damme (1993b) develop an equilibrium selection theory based on the idea that the payoff parameters of a game cannot be observed with certainty. The complete information stag hunt game in Table 2.1 is replaced by a payoff perturbed game: a global stag hunt game. In this game, each player observes the payoff table in Table 2.2 but his/her payoff is determined by the actual table in Table 2.1.

Following (Carlsson and van Damme, 1993a, Section 4), I assume that everything about the stag hunt game is common knowledge except the payoff to the safe choice q. Each player receives a signal $q_i = q + \epsilon_i$ that provides an unbiased estimate of q. The signals are noisy so q is not common knowledge amongst the players. Let q denote a random variable that is distributed on the interval $[a.b]$ where $a < 0$ and $b > 1$. So it is possible that $q > 1$ in which case B strictly dominates A and it is possible that $q < 0$ in which case A strictly dominates B. Let $(\epsilon_1, \epsilon_2, \ldots, \epsilon_n)$ denote an n-tuple of zero mean independently and identically distributed random variables. The ϵ_i are assumed to be independent of q and to be distributed within $[-E, E]$ where $E < -\frac{a}{2}$ and $E < \frac{b-1}{2}$. The incomplete information model is described by the following rules:

1. $(q, \epsilon_1, \epsilon_2, \ldots, \epsilon_n)$ are randomly generated to obtain $(q, q_1, q_2, \ldots, q_n)$.
2. Player i observes q_i and chooses between A and B.
3. Each player i receives payoffs which determined by choices made in step 2 and the actual value of q in Table 2.1 with the mean matching protocol.

Because each player observes different estimated value of q, the only strategy that can be a best response is a threshold strategy. We can show that there exists only one threshold, q^*, that survives iterated elimination of strictly dominated strategies in the Global Stag Hunt Game. If all but player i use a threshold q^*, player i will also use a threshold q^* if his expected payoffs from choosing A and B are the same when observing q^*. His expected payoff from choosing B is q^*. Player j would choose A if $q_j < q^*$ and B if $q_j > q^*$, so player i's expected payoff from choosing A when observing p^* is given by[7]

$$\sum_{k=1}^{n} \frac{p\left(k,n\right) \times \frac{(n-1)!}{(k-1)!(n-k)!}}{2^{(n-1)}},$$

which is the expected value from choosing A when the number of players choosing A is from $\{1, 2, \ldots, n\}$. If we let this equation equals q^*, we can see that $q^* = 0.5$.[8] Remarkably this is true for any $\varepsilon > 0$ that are arbitrary small (smaller than $-\frac{a}{2}$ and $\frac{b-1}{2}$). Carlsson and van Damme's argument thus gives another reason to expect the risk-dominant equilibrium if the players have arbitrarily small uncertainty about q. In the Global Stag Hunt Game, using a threshold of 0.5 is the unique dominance solvable equilibrium. Any thresholds $p \neq 0.5$ cannot be constituted as a mutual best response or an equilibrium for every player in the group. This is because if all players except player i use the same threshold of p, player i's expected payoff from choosing A when observing $q_i = p$ is 0.5 which is not equal to p, the expected payoff from choosing B.

2.2.3 Global Stag Hunt Game Used in the Experiment

In this experiment, I transform the game in Table 2.1 to the game in Table 2.3: $G_2 = 400 \times \{G_1 + 0.25\}$, where G_2 is the game used in the experiment and G_1 is the game in Table 2.1. Our main reason is to avoid decimal points and negative earnings in any periods. We use a group size $n = 8$.

Under complete information, the payoff dominance threshold is 500 and the risk dominance threshold is 300. Under incomplete information, a unique threshold equilibrium Q^* satisfies

[7] $2^{(n-1)}$ is a number of all possible cases from the fact that each player j has the same probability to choose A or B. $p(k,n) = \frac{k-1}{n-1}$ is the payoff when k players including player i choose A. $\frac{(n-1)!}{(k-1)!(n-k)!}$ is a number of cases where k players including player i choose A.

[8] In general, this may not give the same critical value as risk dominance when n is greater than two, but for the mean matching protocol $p^* = 0.5$.

Table 2.3: Version of Global Stag Hunt Game Form Used in the Experiment (a, left) Actual Payoff Table; (b, right) Subject i's Estimated Payoff Table.

	A	B
A	500,500	$100, Q$
B	$Q, 100$	Q, Q

	A	B
A	500,500	$100, Q+E_i$
B	$Q+E_i, 100$	$Q+E_i, Q+E_i$

$$Q^* = \sum_{k=1}^{8} \frac{[100 + \{400 \times (\frac{k-1}{n-1})\}] \times \frac{7!}{(k-1)!(8-k)!}}{2^7}.$$

That is $Q^* = 300$, the risk dominance threshold.

2.3 Experimental Design

The stage game form used in the experiment is given in Table 2.3: each player observed the right table but his/her payoff was determined by the left table. The stage game was played 100 times to give adequate experience for the iterated elimination of strictly dominated strategies to convergence to equilibrium. The values of Q used in the experiment were integers in the interval 0 to 600, that is, $Q \in \{0, 1, 2, \ldots, 600\}$. The sequences of a hundred values of Q were generated by a computer using a uniform distribution. As stated in the instructions, "Many sequences of one hundred Qs were generated. One of these sequences will be used in today's session." The sequence was chosen to be representative of a uniform distribution even in small samples. The units denote twentieths of a cent.

Two treatments were conducted. In the baseline treatment of complete information about Q, $E_i = 0$, that is the observed and the actual table were identical. In the incomplete information treatment, Q was only observed with error. The private signal error was $E_i \in \{-50, -49, \ldots, 49, 50\}$. The sequences were generated in the same way as the Q sequences. The same sequence of $Q + E_i$ was used in all sessions of a treatment, but different sequences were used for the complete information treatment and the incomplete information treatment.

The instructions were read aloud to ensure the game was common information among the participants. After the instructions the participants filled out a questionnaire to establish that the participants knew how to calculate their earnings. There were always mistakes on at least one questionnaire and the section on calculating earnings was always reread to the participants. Many more mistakes were made in the incomplete information treatment than the complete information treatment. The appendix contains the instructions, questionnaire, and screen shots of the graphical user interface. After each period, each subject received feedback on the actual value of q, number of subjects in the cohort who chose A and B, and his/her payoff.

Three sessions of three cohorts, or a total of nine cohorts, were conducted for each treatment. Each cohort consisted of eight participants. Thus, each treatment used 72 participants and the total number of participants was 144. The participants were Texas A&M University undergraduates recruited campus wide using ORSEE, see Greiner (2004).

The experiment was programmed and conducted with the software z-Tree, see Fischbacher (2007). The experiment was conducted in the Economic Research Laboratory at Texas A&M University, which has 36 networked participant stations, in February and March of 2013. A five dollar show up fee plus their earnings in the session were paid to the participants in private and in cash. The average earnings were about $29.19 for a session that lasted between 70 and 90 minutes.

After the decision making portion of the session was completed and while they waited for their earnings to be calculated, participants filled out a questionnaire that asked them to explain their behavior in the session.

2.4 Experimental Results

2.4.1 Basic Results

A useful way to look at the data is with histograms of the frequency of A among a cohort by either the private signal, $Q + E_i$, or Q depending on whether the treatment is complete information or incomplete information. Figures 1 to 18 report the histograms by 25 period intervals for the incomplete information treatment and by 50 period intervals for the complete information treatment. The incomplete information treatment fills more bins, because usually there are eight different observations per period, than the complete information treatment, where all eight observations are for the same Q. Also, there appeared to be more learning going on with incomplete information than complete information.

Cohorts 1 to 9 were conducted under the incomplete information conditions. Looking down the page, one can see how the histograms are changing with experience. Cohorts 1 and 2 in figures 2.1 to 2.4 show evidence of learning to play the unique equilibrium of the incomplete information game, 300; that is, fewer participants are choosing A when the private signal is over 400 in each twenty-five period interval. These two cohorts are the only ones to do this.

Cohort 3 in figures 2.1 to 2.4 is more typical of the results in the incomplete information treatment. In periods 76 to 100, the participants implemented an almost perfect step function at 450, that is, when the private signal was less than 450 everyone in every period choose A, the risky action associated with the payoff-dominant equilibrium, and when the private signal was more than 450 almost everyone in every period choose B.

Cohort 4 in figures 2.5 to 2.8 shows some unraveling towards the unique equilibrium but for signals in (400,450] more than fifty percent of the play is A. Cohorts 5 and 6 in figures 2.5 to 2.8 and Cohorts 7 to 9 in figures 2.9 to 2.12 all converge on a transition from all A to all B at around a private signal of about 450, well above the unique global game equilibrium threshold of 300.

Cohorts 10 to 18 were conducted under the complete information treatment. Cohort 10 in figures 2.13 and 2.14 is perhaps the most remarkable. Cohort 10 coordinated perfectly on payoff dominance as the selection principle, that is, when Q was in [0,500] all eight participants played A in every period from 51 to 100 and when Q was in (500,600] all eight participants played B in every period from 51 to 100. However, Cohort 10 is the only complete information cohort to do this.

Cohort 15's histogram is almost a perfect step function but at Q equals 400. The remaining complete information cohorts all appear to step down at a Q in [400, 500]. The threshold (step down) coordinated on is cohort specific.

2.4.2 Estimated Thresholds

The histograms in figures 2.1 to 2.18 appear to us to have the shape of a logistic function. In order to get a more precise measure of the heterogeneity of the various cohorts, I estimated the following logit model on the cohort data for periods 76 to 100:

$$p(Q+E) = \frac{e^{b_0+b_1(Q+E)}}{1+e^{b_0+b_1(Q+E)}},$$

where $p(Q+E)$ is the probability of A. Table 2.4 reports the estimated parameters and the critical value for the eighteen cohorts. The reported estimate for cohort 12 excludes subject 17, who feel asleep twice, nodded off repeatedly, and appears to have played randomly. In the questionnaire, he wrote that he played randomly, which makes him a self-reported step-0 thinker and not a threshold user.

While it is notable that the two values close to the risk-dominant threshold of 300 occurred in the incomplete information treatment and the one value essentially

Table 2.4: Estimated Logit Models and Critical Values by Cohort for Last 25 Periods.

Cohort	Treatment	b_0	b_1	$Q + E = p^{-1}(0.5)$	Rank
cohort 1	Incomplete	18.193	-0.056	326.9	1
cohort 2	Incomplete	13.617	-0.037	369.3	2
cohort 3	Incomplete	97.956	-0.216	454.8	11
cohort 4	Incomplete	14.551	-0.033	436.8	7
cohort 5	Incomplete	31.069	-0.068	460.3	15
cohort 6	Incomplete	29.868	-0.068	439.8	8
cohort 7	Incomplete	28.753	-0.062	460.1	14
cohort 8	Incomplete	24.569	-0.054	455.5	12
cohort 9	Incomplete	76.780	-0.167	458.9	13
cohort 10	Complete	1195.46	-2.421	494.0	18
cohort 11	Complete	41.826	-0.091	460.6	16
cohort 12	Complete	18.977	-0.047	407.2	4
cohort 13	Complete	32.420	-0.072	453.4	10
cohort 14	Complete	23.003	-0.051	452.8	9
cohort 15	Complete	286.596	-0.716	400.6	3
cohort 16	Complete	18.248	-0.043	422.4	5
cohort 17	Complete	68.294	-0.145	471.8	17
cohort 18	Complete	27.261	-0.063	435.9	6

at the payoff-dominant threshold of 500 occurred in the complete information treatment, I cannot reject the hypothesis that both treatments were drawn from the same distribution. The Mann-Whitney test statistic is 83 for the incomplete information treatment and 88 for the complete information treatment. For significance at the 10 percent level, the test statistic for the incomplete information treatment would have to be less than 71.[9] Most estimated thresholds are around 450 regardless of treatment. A stochastic steady state appears to have emerged for most cohorts with a threshold in the interval [400,500]. These thresholds are cohort specific and would seem difficult to predict on an apriori basis.

Figures 2.19 and 2.20 illustrate the estimated logit models. The lines in the figures show the critical values at which fifty percent of the participants in a cohort are choosing A and fifty percent are choosing B. The incomplete information cohorts have two outliers and seven tightly clustered around 450, while the complete information cohorts have almost a uniform distribution in the [400,500] interval.

2.4.3 Debriefing Questionnaire

After the 100 choices were made, the subjects were asked to complete a debriefing questionnaire consisting of four questions. The first question was, "What strategy did you use while playing this game? Please include details about what led you to choose A or B." The answers were revealing. Seventy-two percent of the subjects in the incomplete information treatment and ninety-two percent of the subjects in the complete information treatment reported using a threshold. For example, a subject reported, "I chose B when the odds were that Q was greater than 500. I used the estimate to decide this." Twenty-five different exact thresholds are mentioned in the 144 subject responses ranging from 300 to 500. One subject used a threshold

[9] See Conover (1980) Table A7. The two-sample t statistic for a difference in treatment means is -0.8, which is also not statistically significant.

of 300, the risk-dominant threshold. The most common exact threshold was chose A if Q is less than 500 and B otherwise. It was chosen by nineteen percent of the subjects. Other popular choices were thresholds at 450, 400, and 440 to 445 in order of decreasing popularity.[10]

The last group, 440 to 445, comes from subjects who best respond to the belief that one opponent chooses B. A typical answer was, "I choose A or B depending on the spread that I was given for choice B. I calculated the costs of one of my 'teammates' deviating from A and choosing B. If one person deviated and I picked A I would receive 442, if 2 picked B I would get 385 and so on. If the bottom boundary of my spread for Q was greater than 442 I choose B. If it was not then I chose A."

Ten percent of the subjects reported what we call a fuzzy threshold. They would chose A for sure if Q was less than w and B for sure if Q was more than z, where $w < z$, and sometimes one or the other for Q in $[w, z]$. For example, a subject wrote, "If B was over 500, I would choose B. If B was under 400 I automatically chose A. If B was between 400 and 500, I debated whether or not to choose B, more times than not deciding to do so."[11]

The second debriefing question was, "Did you change your strategy over time?" Fifty-four percent of the subjects in the incomplete information treatment and two-thirds of the subjects in the complete information treatment reported changing their strategy over time.

The third debriefing question question was, "If you changed your strategy, what

[10]If we treat a strict threshold player as someone who always chose A for Q below some value and always chose B for Q above the same value, then inspecting the individual data reveals that for the last 25 periods 76 percent of the subjects in the incomplete information treatment and 81 percent of the subjects in the complete information treatment were strict threshold players.

[11]Subjects using a fuzzy threshold seem to be engaged in fast and slow thinking popularized by Kahneman (2011). Schotter and Trevino (2013) exploit the difference in measured response time to accurately predict observed individual thresholds in a global game.

made you change it?" The typical response was the behavior of the other players in particular the need to coordinate on the same threshold. For example, a subject wrote, "I was initially choosing the highest number of all those provided, so that was typically A unless B was a higher number. However, through the experiment other participants stopped choosing the highest number ($A = 500$) when B became more than 400." Our interpretation of this quote is that the participant started using what might be called a wishful thinking strategy (Maximax) because they write that the payoff to A was 500. Over time they learned that the group was coordinating on a threshold of 400 and this led them to change their behavior. Reading the debriefing answers from the cohort that perfectly coordinated on the payoff-dominant threshold of 500, cohort 10, I am now convinced that subjects initially started with a wishful thinking strategy rather than any equilibrium concept like payoff dominance. It is only after observing dis-coordination that they begin thinking about how to coordinate with the group.

The forth question asked participants, "If you could play this game again, what would you do?" Fifty-one percent answered that they would do the same thing. Thirty-one percent answered that they would change their strategy especially using the strategy that they adopted at the end of the session earlier. Other frequently mentioned answers include wishing that they could communicate and that they chose A more often.

A comparison of the location of the logit estimate of the group threshold by 25 period bins reveals very little movement in the estimated threshold. For the nine incomplete information cohorts, the average absolute value of the change from the estimated threshold in the first 25 periods and the last 25 periods is 22 units. For the nine complete information cohorts, the average absolute value of the change from the estimated threshold in the first 25 periods and the last 25 periods is also 22 units.

Interestingly, eight out of the nine incomplete information cohorts decline between the first and last 25 periods, that is, in the direction predicted by the theory, while five of nine complete information cohorts increase, which is slightly more than one would expect from chance.

2.4.4 Discussion

We find no significant difference between subjects in complete and incomplete information treatments. The results are positive for efficiency's standpoint; coordination persists in environments with incomplete information. Despite the fact that subjects under incomplete information treatment should conform to the risk-dominant threshold, they deviate significantly toward an efficiency threshold.

It might seem puzzling that there is so little learning in the incomplete information treatment when myopic best-response dynamic theory suggests that subjects should be learning iterated dominance. If we always round down fractions to integers, it takes 20 best response iterations to go from the payoff-dominant assignment of all use a threshold of 500 to the risk-dominant assignment of all use a threshold of 300. Without rounding the process does not converge in a finite number of iterations. But notice that learning iterated dominance requires subjects to move to less efficient outcomes, which previous work suggests subjects are reluctation to do, see Van Huyck, Cook and Battalio (1997).

A calculation of the monetary incentive to deviate from an assignment may explain why subjects are not learning iterated dominance. In the incomplete information treatment, the best response, c^*, to an assignment of all play a threshold p is given by the following equation: $c^* = 60 + \frac{4}{5}p$. Consider an assignment to a threshold strategy combination of all use 450. The best response is a threshold of 420. However, the optimization premium, the monetary incentive to give a best response, is an average of *3.75 units or 0.2 cents*. This calculation is myopic because as behavior converges on 300 the group is moving to less efficient outcomes. If everyone conformed to a threshold of 450, they would each earn \$24.90 for the session. All participants using the risk-dominant threshold of 300, which is what best response learning converges to, would earn an average of \$23.35 for the session, which is a \$1.55 dollar difference for the session and approximately a 1.6 cent difference per period. The lost efficiency is about eight times larger than the monetary incentive to best respond given an assignment to everyone to use 450 as their threshold. Previous work has shown that subjects are reluctant to converge towards less efficient outcomes. This reluctance combined with a low myopic incentive to best respond may explain the similar behavior observed under complete and incomplete information.

The low optimization premium relative to the inefficiency of the unique equilibrium is a property of the equilibrium solution. Scaling up the payoffs will make both larger by the same proportion. This can be seen in figure 2.21, which graphs the Expected Utility of the payoff-dominant threshold, $Eu(q_i|500)$ in red, and the risk-dominant threshold, $Eu(q_i|300)$ in blue, given a realization of q_i. The horizontal axis graphs q_i and the vertical axis graphs $Eu(q_i|p)$. Notice that the Expected Utility function is discontinuous at $Eu(500|500)$. At the payoff-dominant threshold of all play 500 the expected utility from playing A is not 500, because on average half the participants observe a q_j above 500 and play B, which earns 100 per match, and half the participants observe a q_j below 500 and play A, which earns 500 per match, making the expected earnings 300. For observations $q_i \in \{0, 1, \ldots, 448, 449\}$ the player can be sure that in a payoff-dominant assignment all of the other players receive a signal that induces them to play A and they all earn 500. Similar considerations give the risk-dominant, $Eu(q_i|300)$, function.

The dashed line and black dot in the function give the best response, 460, to an assignment of all play 500. The area of the shaded triangle gives the expected earnings gained from deviating from the assignment to the best response. The difference between playing 460 and 500 is from observations $q_i \in \{460, 461, \ldots, 498, 499\}$ in which strategy 460 plays B while strategy 500 plays A. The average expected earnings lost from playing 500 is 6.67 (from the triangle area, 4,000, divided by 600). The area of the shaded polygon minuses the area of the shaded triangle gives the expected earnings lost from moving from the payoff dominance to the risk dominance (and global games solution). This loss is, on average, 33.33 or about five times larger than the gains from playing 460 instead of 500 when all other players play 500. Scaling the payoffs from 600 to 6,000 or 600,000 will not change the relative areas of the two shapes.

2.5 Literature Review

There is a large literature on repeated stag hunt games, see Battalio, Samuelson and Van Huyck (2001) for references. Rankin, Van Huyck and Battalio (2000) estimate thresholds from individual data from an experiment with similar stag hunt games, that is, in terms of this paper for $100 < Q < 500$. They find that most subjects can coordinate on high thresholds which are close to the payoff-dominant equilibrium. Stahl and Van Huyck (2002) using finite mixture models reject the threshold specification in favor of learning conditional behavior from individual data from an experiment with two ranges of experience: one with $100 < Q < 500$ and one with $300 < Q < 500$. They find that experiencing with a greater range of Stag Hunt games increases the likelihood of coordinating on high thresholds. Other differences include using random matching in Rankin, Van Huyck and Battalio (2000) and mean matching in Stahl and Van Huyck (2002) and this paper. The answers to the debriefing questionnaire used in the experiment strongly support the view that subjects are using threshold strategies over learning conditional behavior.

Most of the experimental literature which tests global games predictions focuses on variations of the speculative attack model of Morris and Shin (1998). In this game, an individual has two choices: 'attack' and 'not attack'. A player who attacks has an opportunity cost T. If a sufficient number of players choose to attack, they succeed and each of the attacking agents earns an amount Y. They assume that the number of players needed for a successful attack is a non-increasing function in Y. In this game, if $Y < T$, the dominant strategy is 'not attack'. There exists $\bar{Y}$ such that for $Y > \bar{Y}$, the dominant strategy is 'attack'. For Y such that $T < Y < \bar{Y}$, there are two pure Nash Equilibria, all 'attack' and all 'not attack'. The value of Y varied from period to period. The first test of global games predictions in the speculative attack model was Heinemann, Nagel and Ockenfels (2004). They could not find a threshold difference between two treatments. However, they find equilibrium multiplicity under common information treatment but uniqueness under private information treatment. The unique equilibrium that they find under private information treatment is different from my results which suggests equilibrium multiplicity. Cornand (2006) considers two treatments in which subjects can observe two signals. In one treatment, subjects observe both private and common signals whereas subjects in another treatment observe two common signals. She finds that in the treatment with both private and common information, subjects use the public signal as a focal point.

Crawford, Costa-Gomes and Iriberri (2010) criticizes the global games approach on two grounds. First, there is no evidence that people initially perceive the uncertainty in a game as if they were playing a global game, that is, an incomplete information version of the game with special payoff perturbations. Instead, the incomplete information in a global games analysis is constructed to allow the iterated dominance argument. Second, the experimental evidence surveyed in their paper suggests that people stop far short of the many steps of iterated dominance that is needed to make a global games analysis yield a precise prediction. These two reasons could explain why subjects can coordinate under incomplete information in my experiment.

2.6 Conclusion

It has been shown that a Pareto superior equilibrium can be attained when playing a sequence of similar stag hunt games with complete information. However, precise information may not always be available or it may be too costly to obtain. This paper tests whether such coordination would presevere with less precise information. Therefore, I run an experiment where each subject plays a sequence of perturbed stag hunt games with either complete or incomplete information. Under complete information, there is one cohort in which all eight subjects select the choices that are consistent with payoff dominance in the last 50 periods. All other cohorts use thresholds that are closer to the payoff dominance than the risk dominance.

Under incomplete information, the theory of global games has shown that subjects should conform to a unique dominance solvable equilibrium that is risk-dominant. However, only one cohort uses a threshold closes to this prediction. All other cohorts deviate significantly from the prediction and coordinate just as well as subjects in the complete information treatment. Under incomplete information, iterated elimination of dominated strategies forces the players to conform to a unique dominance solvable equilibrium. However, both estimated thresholds and self-report reveal little tendency to converge to that equilibrium.

It might seem puzzling that subjects in the incomplete information treatment do not converge to the theoretical prediction when myopic best-response dynamic theory suggests that subjects should be learning iterated dominance. One explanation could be that the gains from playing best response are small compared to the efficiency loss from moving to the equilibrium, so they would rather coordinate on high thresholds.[12] Another explanation could be that subjects may treat the imprecise information as if it were precise and play accordingly. We leave it as a future extension of my work to experimentally investigate which explanation explains the results better.

For efficiency's standpoint, my results are quite positive because they suggest that coordination on socially desirable outcomes can be reached without having to spend resources to obtain precise information. One open question is to consider if people would pay to know the information with precision. Based on my results, the benefit from doing so is small, which suggests that they should not be willing to pay unless the cost is rather low.

[12] Previous work suggests subjects are reluctant to play best response when it requires them to move to less efficient outcomes, see Van Huyck, Cook and Battalio (1997) for example.

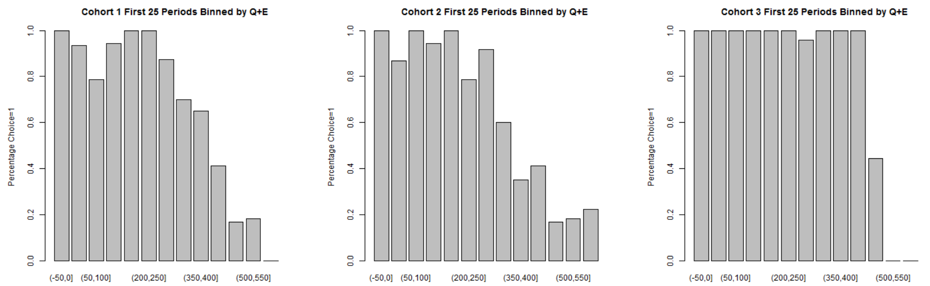

Figure 2.1: Cohorts 1 to 3 Periods 1 to 25

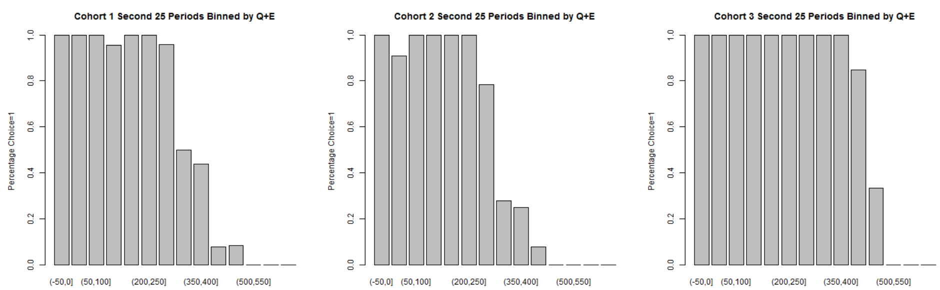

Figure 2.2: Cohorts 1 to 3 Periods 26 to 50

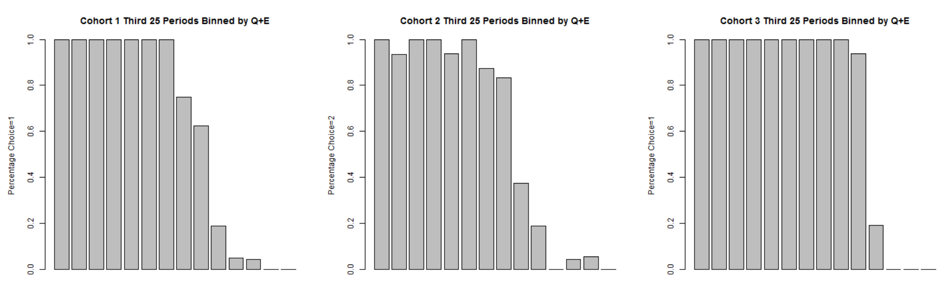

Figure 2.3: Cohorts 1 to 3 Periods 51 to 75

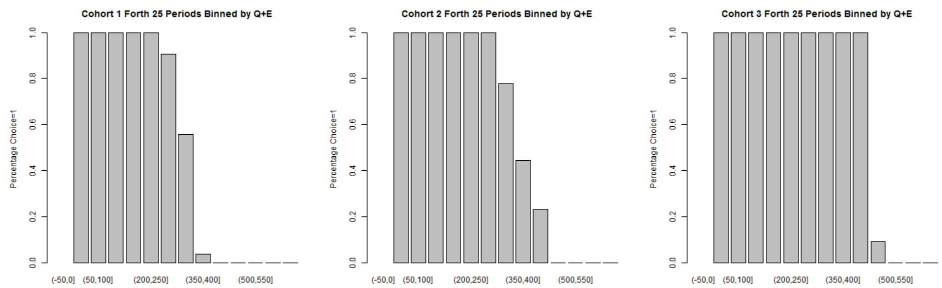

Figure 2.4: Cohorts 1 to 3 Periods 76 to 100

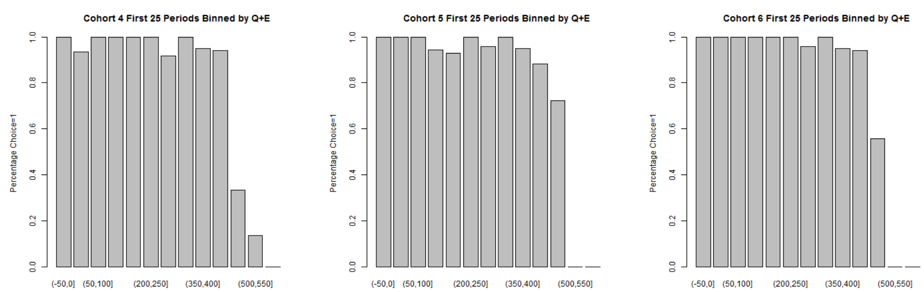

Figure 2.5: Cohorts 4 to 6 Periods 1 to 25

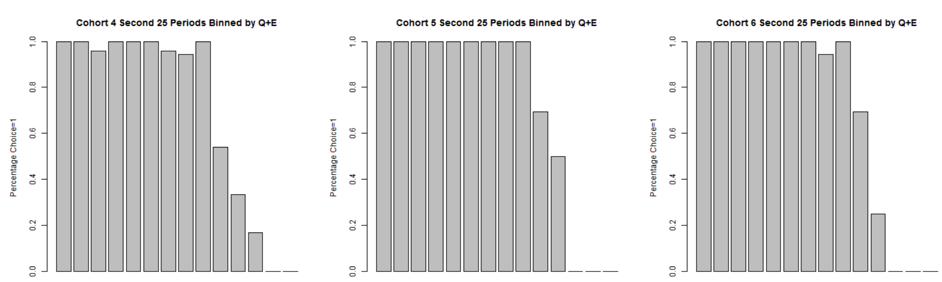

Figure 2.6: Cohorts 4 to 6 Periods 26 to 50

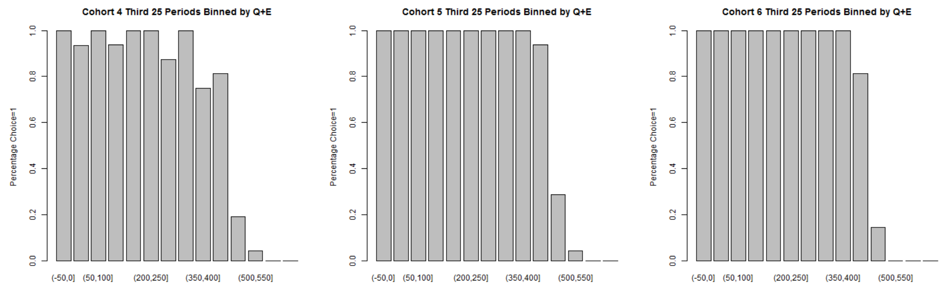

Figure 2.7: Cohorts 4 to 6 Periods 51 to 75

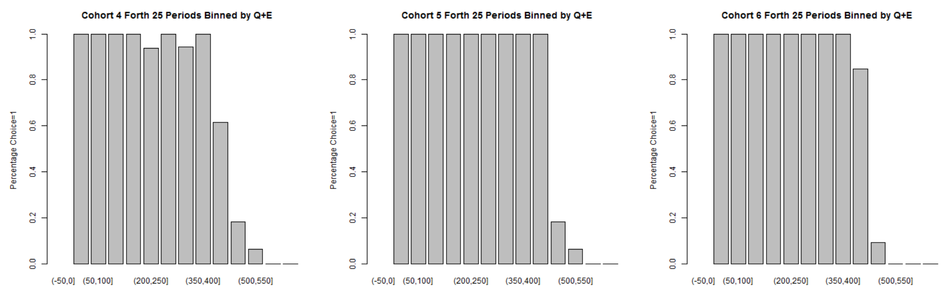

Figure 2.8: Cohorts 4 to 6 Periods 76 to 100

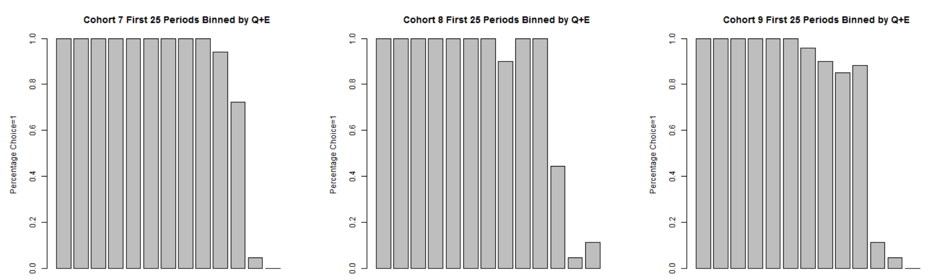

Figure 2.9: Cohorts 7 to 9 Periods 1 to 25

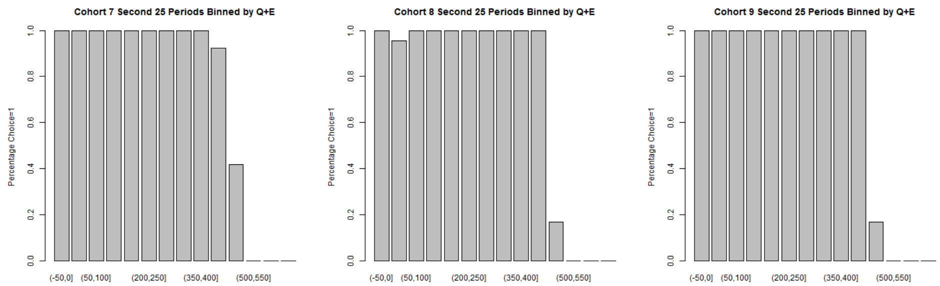

Figure 2.10: Cohorts 7 to 9 Periods 26 to 50

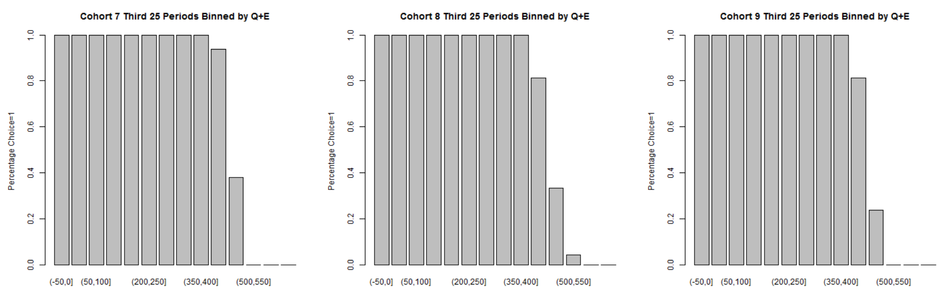

Figure 2.11: Cohorts 7 to 9 Periods 51 to 75

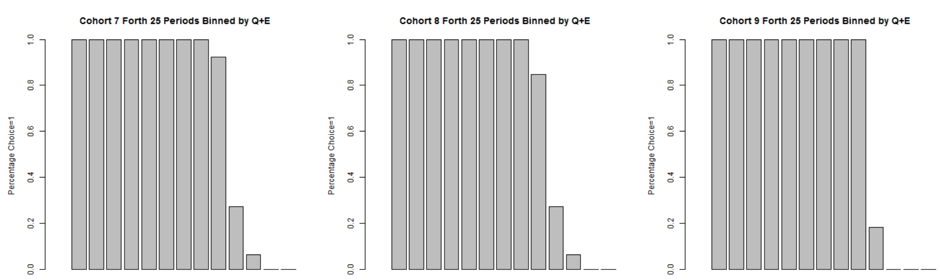

Figure 2.12: Cohorts 7 to 9 Periods 76 to 100

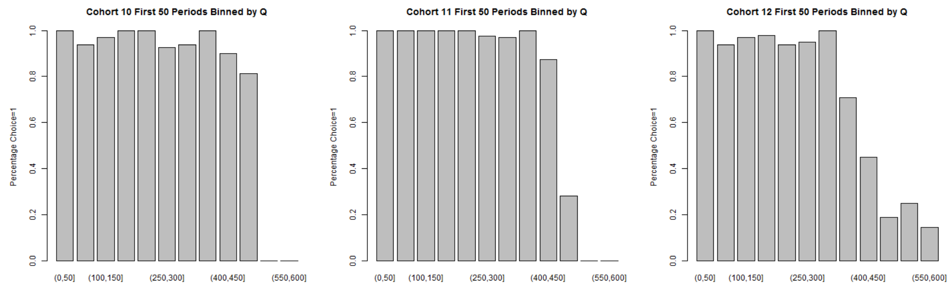

Figure 2.13: Cohorts 10 to 12 Periods 1 to 50

Figure 2.14: Cohorts 10 to 12 Periods 51 to 100

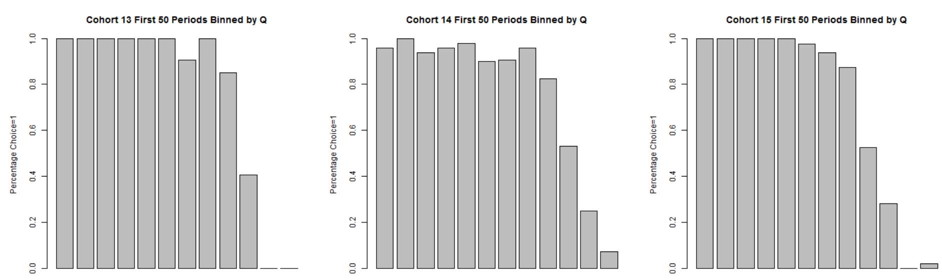

Figure 2.15: Cohorts 13 to 15 Periods 1 to 50

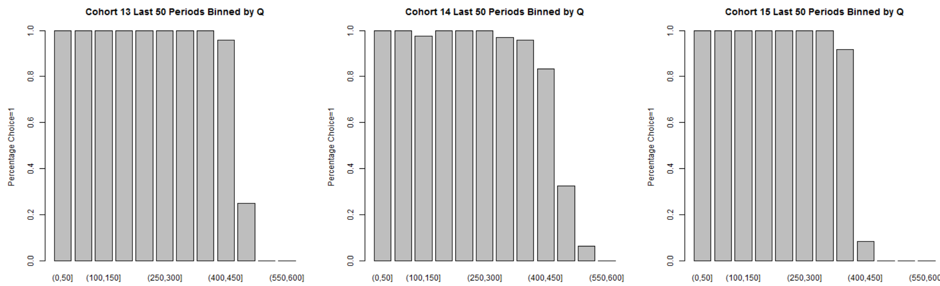

Figure 2.16: Cohorts 13 to 15 Periods 51 to 100

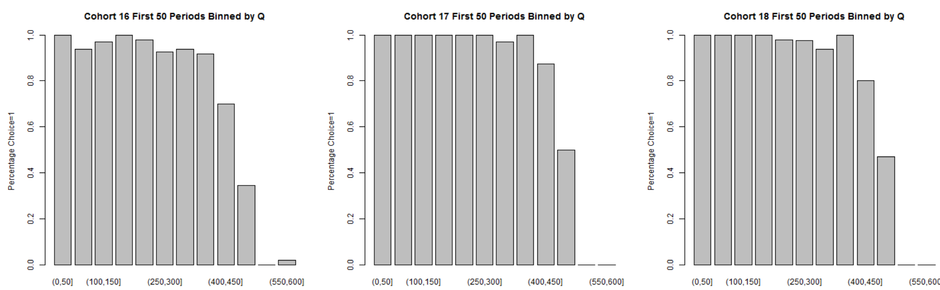

Figure 2.17: Cohorts 16 to 18 Periods 1 to 50

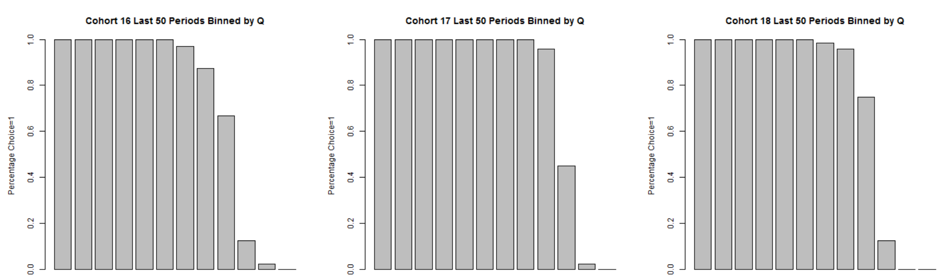

Figure 2.18: Cohorts 16 to 18 Periods 51 to 100

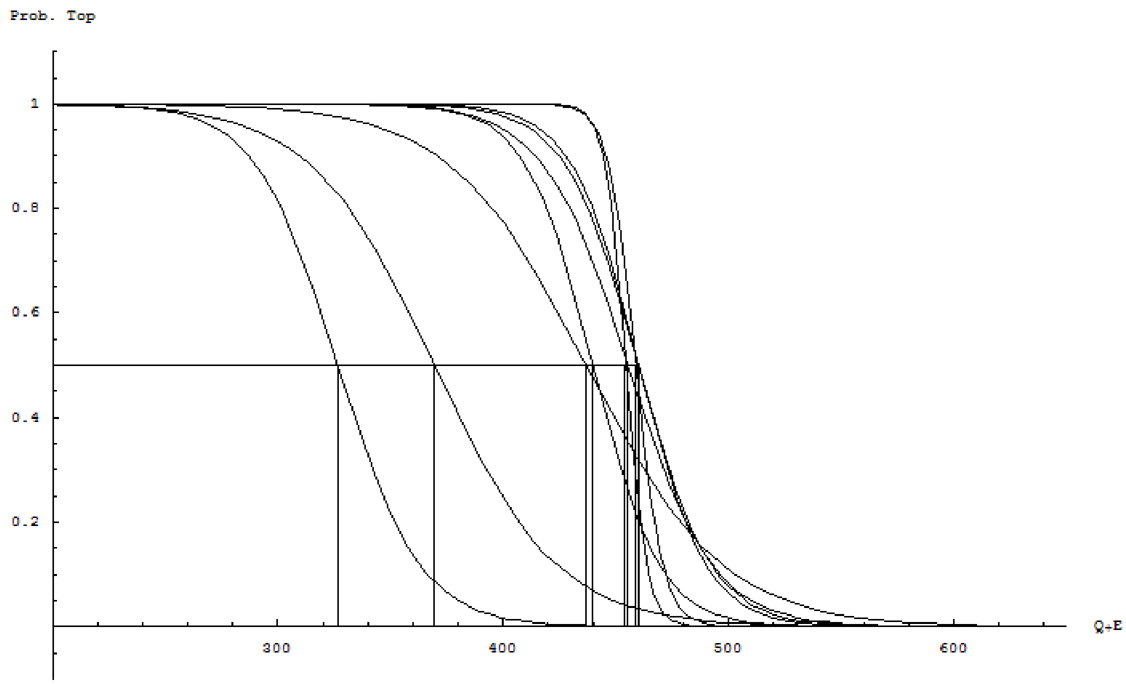

Figure 2.19: Estimated Probability of Choosing A given the Value of $Q + E_i$, Logit Models: Incomplete Information Treatment

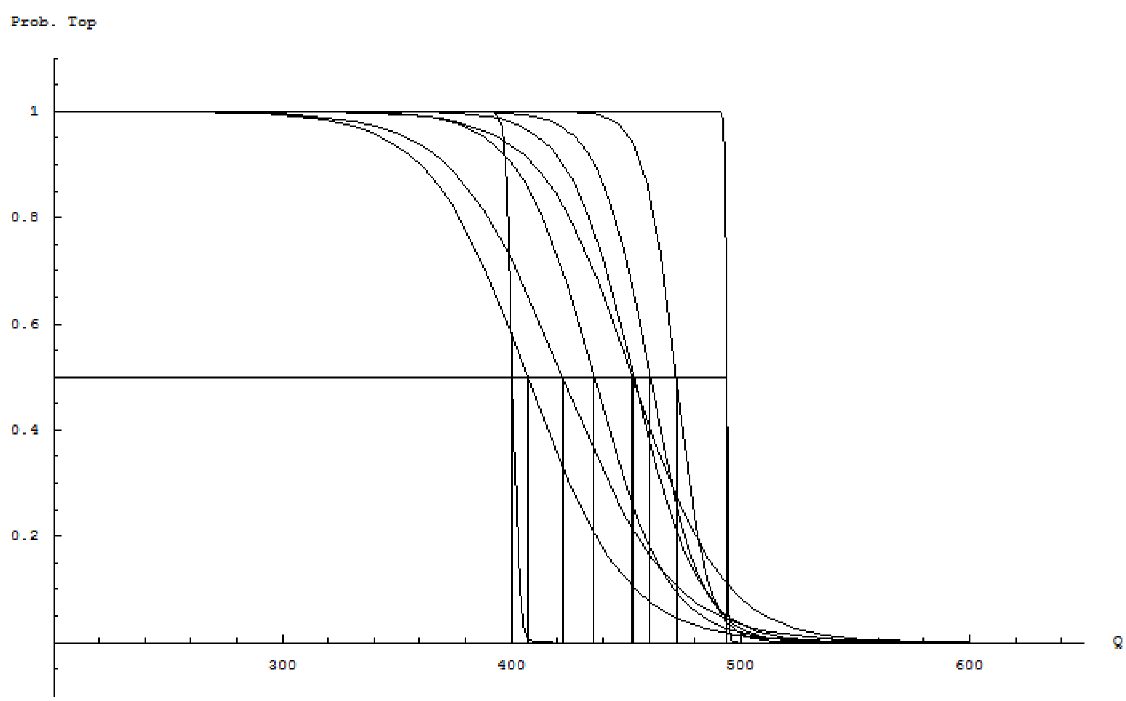

Figure 2.20: Estimated Probability of Choosing A given the value of Q, Logit Models: Complete Information Treatment

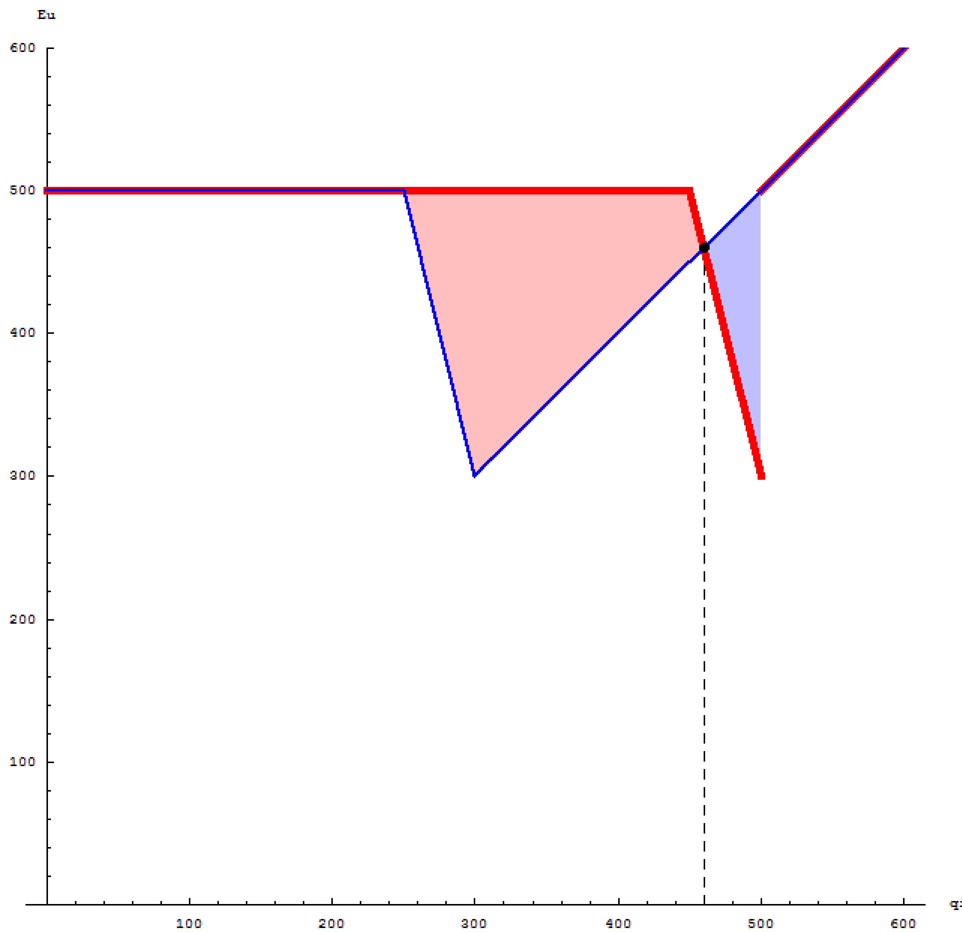

Figure 2.21: The $Eu(q_i|500)$ Function and the $Eu(q_i|300)$ Function.

3. PRUDENCE, JUSTICE, AND BENEVOLENCE: EVIDENCE FROM REPEATED GLOBAL BARGAINING GAMES

3.1 Introduction

Bargaining problems usually result in multiple, mutually inconsistent ways to divide a surplus. Bargaining problems with multiple equilibria result in a particularly difficult strategy coordination problem, because people may fundamentally disagree about the desirability of the different equilibria. Many economists thought that bargaining problems were inherently intractable; see Edgeworth (1881) for an early formalization of the problem. Many equilibrium selection principles have been proposed to select a unique equilibrium including Utilitarian (select the equilibrium with the largest payoff sum), Rawlsian (select the equilibrium that maximizes the welfare of the worst off player), and risk dominance (select the equilibrium with the larger basin of attraction). However, Carlsson and van Damme (1993b) show that if we introduce noise to the payoffs, creating incomplete information versions of standard bargaining problems called global bargaining games, there exists a unique equilibrium that is typically the equilibrium selected by risk dominance. Therefore, we would expect risk dominance to be more salient under incomplete information.

This paper reports an experiment where each subject plays a sequence of perturbed bargaining games in one of two information conditions: complete and incomplete information. The bargaining game models a situation in which players have two ways to divide a surplus: if both players select the same choice, the surplus is divided according to that particular choice. However, if two players fail to coordinate on the same choice and select different choices, each player earns a small fixed payoff. In most games, there are two strict equilibria, one of which is risk-dominant. The

Table 3.1: A Class of Bargaining Games

	A	B
A	W, X	100, 100
B	100, 100	Y, Z

results show that risk dominance performs the best in predicting subjects' choices. Moreover, risk dominance (which is also a global games prediction) is more salient under incomplete information. The results also imply that the "social preferences" of groups differ under different information conditions.

The class of bargaining games depicted in Table 3.1 models a situation in which players have two choices, A and B, to divide a surplus. If players select the same choice, the surplus is divided according to that particular choice. However, if two players select different choices, each player earns a fixed but small payoff for a miscoordination. This results in a multiplicity of Nash equilibria: (A, A) or (B, B). Which equilibrium will be selected by the players would depend on the payoffs according to each equilibrium; i.e., the values of W, X, Y, Z. There are at least three equilibrium selection principles that have been proposed to select a unique equilibrium: Utilitarian , Rawlsian, and risk dominance. Utilitarian selects the equilibrium with the largest payoff sum; Rawlsian selects the equilibrium that maximizes the welfare of the worst off player; and risk dominance selects the equilibrium with the larger basin of attraction.[1] It is unclear which of the three principles is the most salient in predicting players' behavior in a bargaining game.

However, in many situations, subjects may not be able to observe payoffs with precision.[2] There is some evidence that players behave differently in games with complete and incomplete information. Therefore, I introduce noise to the payoffs, as in

[1]In a 2×2 game, a basin of attraction refers to a product of deviation losses

[2]For example, a buyers and a seller may not know each other's willingness to buy or to sell.

the theory of global games introduced by Carlsson and van Damme (1993b). In global bargaining games, each player independently observes the payoffs of W, X, Y, Z, with noise in each period. Carlsson and van Damme (1993b) show that under certain conditions, there exists a unique equilibrium that is often the equilibrium selected by risk dominance. Neither Utilitarian equilibrium nor Rawlsian equilibrium exists under incomplete information since players may observe different payoffs which can lead to different strategies. Therefore, I would expect risk dominance to be more salient under incomplete information.

Given different theoretical predictions under the two information conditions, I conduct an experiment where each subject plays a series of perturbed bargaining games in one of two treatments: complete information and incomplete information. Under complete information, subjects observe the actual payoffs with certainty while under incomplete information, subjects only observe the payoffs with noise that is uniformly distributed with zero mean.

The results show that the Rawlsian principle performs better than the Utilitarian principle in predicting subjects' choices under both conditions. Risk dominance performs the best under both information conditions, but it is not statistically different from Rawlsian under the complete information condition. One approach to analyzing the behavior of subjects is to classify them by type. Foe example, those whose bahavior is consistent with the Utilitarian principle would be classified as the Utilitarian type. We use a finite mixture model regression to estimate the fraction of behavior that is consistent with each type. Half of the subjects under complete information and two thirds of the subjects under incomplete information can be classified, using a finite mixture model of subject types, as the risk dominance type. The results support the global games theory, which predicts a unique equilibrium, risk dominance, in the game with incomplete information. The results also imply that different behavior may occur when subjects observe different information; players may select equilibria with different criteria under different information conditions.

To my knowledge, this paper is the first to compare three equilibrium selection principles and examine the predictions of global game theory in bargaining games. It is also the first to compare the results of the game with complete information to those with incomplete information. The closest paper to mine, Van Huyck and Battalio (2002), only examines the bargaining game under complete information. Moreover, they vary the payoffs with special properties: all games have two strict, efficient equilibria in which the Rawlsian principle selects one equilibrium and the Utilitarian principle selects another equilibrium. Security is varied so that risk dominance selects the Utilitarian equilibrium half the time and the Rawlsian half the time. They observe, in contrast with my paper, more emergence of a Utilitarian convention than a Rawlsian convention, and there is no emergence of a risk dominance convention.

In summary, this paper considers a sequence of perturbed bargaining games in two treatments: complete information and incomplete information. The results show that risk dominance is best in predicting choices; comparing between Rawlsian and Utilitarian principles, the strategies are more consistent with Rawlsian than Utilitarian . Moreover, risk dominance is more salient under incomplete information than complete information. This supports the global games theory which predicts a unique equilibrium, in games with incomplete information, to be the same as the risk-dominant equilibrium. The results also suggest that players may use different strategies against games with different information conditions.

3.2 Related Literature

There is a great deal of on bargaining experiments. Most studies consider a single fixed game where players bargain over a fixed sum of payoffs; see Roth (1995) and (Camerer, 2003, p. 151-198) for surveys. Most experimental results show that splitting surplus equally is a salient norm (the 50-50 norm); see Janssen (2006) and Andreoni and Bernheim (2009) for example. One exception is the experiments by Van Huyck et al. (1995) where participants play symmetric bargaining games with the same earnings matrix every period. In their DS game, they observe unequal-division conventions emerging even though equal-division is an efficient strict equilibrium. They argue that security reduces the salience of the equal division and can drive a laboratory cohort toward an unequal division convention.

Most experimental work on bargaining (and other games) considers a single fixed game. Crawford (2002) argues that "real analogies are seldom this perfect and how players learn from others' behavior in games that are similar but not identical is an important open question".[3] Van Huyck and Battalio (2002) study a class of 2×2 asymmetric bargaining games. In their experiments, participants play similar, but not identical, bargaining games for 70 periods. All games have two strict efficient equilibria in which the Rawlsian principle selects one equilibrium and the Utilitarian principle selects another equilibrium. Risk dominance selects a Utilitarian equilibrium in odd periods (U-games) and a Rawlsian in even periods (R-games). In contrast to my paper, they observe more emergence of the Utilitarian convention than either the Rawlsian or risk dominance convention. From 26 eight-person cohorts, four cohorts converge to the Utilitarian convention for both U and R games while only one cohort converges to the Rawlsian convention for both U and R games. There is no cohort that converges to the risk dominance convention in which it converges to the Utilitarian convention for U games and to Rawlsian convention for R games. If considering either U-games or R-games separately, 15 cohorts converge to

[3] Rankin, Van Huyck and Battalio (2000) opened an investigation of this issue with similar stag hunt games.

the Utilitarian convention for U-games while only 8 cohorts converge to the Rawlsian convention for R-games.

Our paper is also related to Charness and Rabin (2002) who study two-person dictator games. In my experiments, two players decide simultaneously between two choices. One player needs to sacrifice some of his payoffs to coordinate on the same choice with another player, in order for both players to receive higher payoffs than the disagreement payoffs. However, in Charness and Rabin (2002) only one player (a dictator) can choose between two allocations. They show that many subjects are willing to sacrifice some of their payoffs to help their counterparts. For example, about half of the subjects select (375,750) over (400,400) and about one third of the subjects select (500,700) over (600,300).[4]

Lastly, this paper is also related to the global games theory. Most of the experimental literature testing global games predictions focuses on variations of the speculative attack model of Morris and Shin (1998). Heinemann, Nagel and Ockenfels (2004) is the first experimental paper to test this prediction; they find that subjects use different strategies under complete information but similar strategies under incomplete information.

3.3 Analytical Framework

In order to focus the analysis, consider the following game. Table 3.1 describes the game where two players make a decision simultaneously between choice A and choice B. If both players select A (B), the row player will earn W (Y) and the column player will earn X (Z). If two players select different choices (i.e., one player selects choice A and another player selects choice B), each of them earns a fixed payoff of 100 as a disagreement payoff. When W, X, Y, Z are greater than a disagreement

[4]For number in parentheses (A, B): A refers to the payoff of the dictator and B refers to the payoff of the other player.

payoff of 100, there exist two strict Nash equilibria which are (A, A) and (B, B). If $W > Y$ and $X > Z$, both players prefer an equilibrium (A, A). In this situation, it is obvious that A will be selected by both players. To avoid these situations, I assume W to be greater than both Y and Z; and X to be smaller than both Y and Z; i.e., $Y, Z \in (X, W)$. In this case, the row player earns higher payoff with (A, A) while the column player earns higher payoff with (B, B).

3.3.1 Equilibrium Selection Principles

In a bargaining game shown in Table 3.1, there are two strict equilibria in pure strategies: (A, A) and (B, B). Many equilibrium selection principles have been proposed to select an equilibrium when there are multiple equilibria. One of the principles that has been widely used is payoff dominance. It compares the efficiency of equilibria and selects the equilibrium that all players earn the most. In this game, because the row player earns more with (A, A) while the column player earns more with (B, B); there is no payoff-dominant equilibrium.

Harsanyi and Selten (1988) develop risk dominance as the selection criterion when payoff dominance fails to make a unique prediction. In 2×2 games, risk dominance is equivalent to choosing the equilibrium with the larger basin of attraction under best-response dynamics.[5] In other words, it selects the equilibrium with the larger product of the deviation losses. In this game, risk dominance selects (A, A) when $(W-100)\times(X-100) > (Y-100)\times(Z-100)$ and (B, B) when $(W-100)\times(X-100) < (Y-100)\times(Z-100)$.

There are at least two other equilibrium selection principles that have been widely used in bargaining contents: Rawlsian and Utilitarian. The Rawlsian principle (Rawls (1971)) selects the equilibrium that maximizes the payoff of the worst off

[5]This prediction is the same to Nash's bargaining solution (Nash (1951)) which compares the product of utility differences between the agreement and the disagreement point.

Table 3.2: A Class of Global Bargaining Games (a, left) Actual Payoff Table; (b, right) Subject i's Estimated Payoff Table.

	A	B
A	W, X	100, 100
B	100, 100	Y, Z

	A	B
A	W_i, X_i	100, 100
B	100, 100	Y_i, Z_i

player; it selects (B, B) in this game because Y and Z are both greater than X. The Utilitarian principle selects the equilibrium with the largest payoff sum; it selects (A, A) when $W + X > Y + Z$ and (B, B) when $W + X < Y + Z$.

With these three equilibrium selection principles, all games have one of the three possibilities: (1) all three principles select (B, B); (2) Utilitarian selects (A, A) while Rawlsian and risk dominance select (B, B); and (3) Utilitarian and risk dominance select (A, A) while Rawlsian selects (B, B). Note that (1) Rawlsian always selects (B, B) since Y and Z are both greater than X; and (2) the case in which risk dominance selects (A, A) while Rawlsian and Utilitarian select (B, B) is not possible.[6]

3.3.2 Global Bargaining Games

Carlsson and van Damme (1993b) develop an equilibrium selection theory (a global game) based on the idea that the payoff parameters of a game cannot be observed with certainty. The complete information bargaining game in Table 3.1 is replaced by a payoff perturbed game: a global bargaining game, as in Table 3.2. The global game can be described by the following steps:

1. Nature selects W, X, Y, Z.

[6]Suppose that Utilitarian selects (B, B), we know that $Y + Z > W + X$. Because $Y, Z \in (X, W)$ and let $W = a+Y$ where a is a constant; we have $Z > X+a$. We can construct $(Y-100)\times(Z-100) > (W - 100 - a) \times (X - 100 + a) = (W - 100) \times (X - 100) + a(W - X - a) > (W - 100) \times (X - 100)$ since $W - a = Y > X$. Therefore, $(Y - 100) \times (Z - 100 > (W - 100) \times (X - 100)$. In this case, risk dominance would select (B, B). This implies that if Utilitarian and Rawlsian agree on the same equilibrium, risk dominance would predict that equilibrium as well.

2. Each player independently observes W, X, Y, Z with some noise, so we denote them as W_i, X_i, Y_i, Z_i for subject i.

3. Each player chooses between A and B simultaneously.

4. Each player receives payoffs as determined by the game form in step 1 and all players' choices in step 3.

In other words, player i observes a game on Table 3.2b but the payoffs are determined by a game on Table 3.2a. Carlsson and van Damme (1993b) show that for any 2×2 game, under some restrictions, iterated elimination of dominated strategies in the global game forces each player to select an equilibrium equivalent to the risk dominance criterion. The restrictions are (1) the initial subclass of games is large enough and contains games with different equilibrium structures, and (2) the noise is independently distributed and is sufficiently small. [7]

Under incomplete information (i.e., global bargaining games), there exists a unique equilibrium that is the same as the equilibrium derived from the risk dominance criterion. Other equilibrium selection principles including Rawlsian and Utilitarian are no longer equilibria because observing different parameters can lead to different choices.

A global game does not imply that players always coordinate on the risk-dominant equilibrium of the actual game even though they play the same strategies. In fact, each player selects the risk-dominant equilibrium according to each player's estimated payoff game, which may end up with different strategies in some situations. However, coordination on the actual game is ensured when noise vanishes.

[7] See Carlsson and van Damme (1993b) for details of the proof.

3.3.3 Non-Equilibrium Concepts

Experimental evidence suggests that people often deviate systematically from equilibrium, especially when they have no experience with the game. Stahl and Wilson (1994, 1995) and Nagel (1995) introduce a non-equilibrium model based on level-k thinking. In this model, level-0 thinkers play uniformly over their action set, level-1 thinkers best respond to a belief that everyone else is a level-0 thinker, level-2 thinkers best respond to a belief that everyone else is a level-1 thinker, and so on. In this bargaining game, level 0 thinkers would play A and B with equal probability. A level 1 row player would choose A because her expected payoff of playing A, $(0.5 \times W) + (0.5 \times 100)$, is higher than her expected payoff of playing B, $(0.5 \times 100) + (0.5 \times Y)$ since $W > Y$. Similarly, a level 1 column player would choose B since $Z > X$. Level 2 row players would match the choice of level 1 column player and choose B, while level 2 column players would choose A. Therefore, odd-step thinkers (level 1, 3, 5, ...) select T if playing as row players and select B if playing as column players, while even-step thinkers (level 2, 4, 6, ...) select B if playing as row players and select A if playing as column players. A pair will select the same choice when the difference between their levels is an odd number and different choices when it is an even number.[8]

An even more naive theory is maximax, where a player attempts to earn the maximum possible benefit available as if all other players will also act so as to maximize her payoff. In other words, player i picks the strategy s_i which maximizes a payoff $g_i(s_i, s_{-i})$ over all possible $(s_i, s_{-i}) \in S_i \times S_{-i}$. In previous chapter, the most common strategy described in the debriefing questionnaire of a global stag hunt game was maximax. In the global bargaining game, maximax results in the row player

[8] If at least one player is a step-0 thinker, the coordination will be successful half of the time.

selecting A and the column player selecting B; that is, it results in discoordination, unlike the global stag hunt game. Hence, if players bring this decision rule into the laboratory they will have to then learn a more sophisticated strategy to successfully coordinate on a pure strategy equilibrium.

3.4 Experimental Design

To accommodate the requirement of global games theory that the initial subclass of games contains games with different equilibrium structures, I let the values of W, X, Y, and Z used in the experiment to be integers in the interval 0 to 600, that is, $W, X, Y, Z \in \{0, 1, 2, \ldots, 600\}$. In order to compare a treatment with complete information to a treatment with incomplete information, I used the same values under both conditions. The stage game form used in the experiment is given in Table 3.3. participants in a treatment with complete information observed the actual payoff table as in Table 3.3a, while participants in a treatment with incomplete information only observed the estimated payoff table as in Table 3.3b.

The stage game was played for 100 periods to give adequate experience to learn to solve a multiple equilibria problem. In each period, four values were generated using a uniform distribution between 0 and 600. Since I have a restriction that $Y, Z \in (X, W)$, I set W equal to the largest value, X equal to the smallest value, and Y and Z equal to either the second or the third largest value (with equal probability). In each period, each player was assigned a role as either a row or a column player; however, the payoff table was shown on each player's screen as if he/she was always a row player. In addition, action labels were also scrambled to prevent players from using non-strategic details to solve their coordination problem.

Two treatments were conducted in this paper. In the baseline treatment of complete information about the payoff table, every player observed the actual table; that

Table 3.3: A Global Bargaining Game Form Used in the Experiment ($600 > W > \{Y, Z\} > X > 0$) (a, left) Actual Payoff Table; (b, right) Subject i's Estimated Payoff Table.

	A	B
A	W, X	100, 100
B	100, 100	Y, Z

	A	B
A	W_i, X_i	100, 100
B	100, 100	Y_i, Z_i

is $W_i = W$, $X_i = X$, $Y_i = Y$ and $Z_i = Z$. In the incomplete information treatment, the payoff table was only observed with noise. Each player i observes the private estimate values of W, X, Y, Z, which we denote W_i, X_i, Y_i, Z_i. The private value of W_i was $W_i \in \{W - 50, W - 49, \ldots, W + 49, W + 50\}$. Note that W_i and W_j, for players i and j, were generated separately, and they were very likely to be different values in each period. The private values of X_i, Y_i, Z_i were generated in the same manner as W_i. So, in each period, 32 error terms (integers between -50 and 50) were generated: four values (for W, X, Y, Z) for each of eight players in a cohort. The same sequence of the actual payoff tables was used for all cohorts under both information treatments, and the same sequence of the error terms was used in all cohorts under the incomplete information treatment. The only difference between the two treatments was that players in the incomplete information treatment observed the payoff tables with errors, while players in the complete information treatment observed the actual payoff tables.

Each participant was randomly matched with a new counterpart in each period, within a cohort of eight participants. After each period, each participant received feedback on the actual payoff table (for the incomplete information treatment), her and her counterpart's choices, and the earnings for that period for her and her counterpart. Participants were paid for all 100 periods with the exchange rate of 12 points for a cent.

Two sessions of three cohorts and one session of two cohorts for a total of eight cohorts were conducted for each treatment. Each cohort consisted of eight participants. Thus, each treatment has 64 participants and the total number of participants was 128. The participants were Texas A&M University undergraduate students recruited campus wide using ORSEE, see Greiner (2004).

The instructions were both shown on screen and read aloud to ensure the game was common information among the participants. After the instructions, the participants filled out a questionnaire to establish that they knew how to calculate their earnings. In sessions with any mistakes on any questionnaires, the section on calculating earnings was reread to the participants to ensure that they understood how to play the game.

The experiment was programmed and conducted with the software z-Tree, see Fischbacher (2007). The experiment was conducted in the Economic Research Laboratory (ERL) at Texas A&M University in June 2013. A five dollar show up payment plus their earnings in the session were paid privately to the participants in cash. The average earnings is \$25.54 for a session that lasted about 2 hours.

After the decision making portion of the session was completed and while they waited for their earnings to be calculated, participants filled out a second questionnaire that asked them to explain their behavior in the session.

3.5 Experimental Results

Subjects in my experiments played a sequence of 100 global bargaining games. Because I allowed the agreement payoffs to be less than 100, in some games there exists a unique Nash equilibrium as either (A, B) or (B, B).[9] Sections 5.1 and 5.2 consider basic results and type classification, respectively. Section 5.3 reports a

[9]Since I scrambled the action labels, (A, B) may be labeled (B, A) and (B, B) may be labeled (A, A).

Table 3.4: Percentages of Decisions that Comply with Each Equilibrium Selection Principle by Cohorts

Cohort	Treatment	Risk Dominance	Utilitarian	Rawlsian	Maximax
1	Incomplete	73%	66%	57%	52%
2	Incomplete	68%	52%	76%	51%
3	Incomplete	72%	57%	74%	55%
4	Incomplete	65%	54%	63%	50%
5	Incomplete	77%	68%	61%	53%
6	Incomplete	72%	57%	68%	53%
7	Incomplete	70%	60%	63%	60%
8	Incomplete	75%	64%	64%	54%
1-8	Average	71%	60%	66%	54%
9	Complete	73%	65%	63%	56%
10	Complete	68%	48%	80%	50%
11	Complete	68%	54%	73%	51%
12	Complete	68%	56%	68%	55%
13	Complete	71%	60%	68%	54%
14	Complete	68%	65%	63%	50%
15	Complete	67%	56%	73%	52%
16	Complete	72%	65%	65%	53%
9-16	Average	69%	59%	69%	53%

debriefing questionnaire about how subjects played this game.

3.5.1 Basic Results

A useful way to look at the data is to look at how accurate each equilibrium selection principle is in predicting players' choices. We will consider only the periods that the earnings table has $W_i > \{Y_i, Z_i\} > X_i > 100$ because there are two strict Nash Equilibria and these equilibria cannot be Pareto ranked. Fifty-three games under complete information and thirty-five to forty-five games under incomplete information have this property.[10] If we randomly select a choice, either A or B,

[10]Under incomplete information, each player observes different estimate earnings table, that is why the number of games that satisfy my restriction are different.

made by a player in each period, we should have a correct prediction half of the time. Since each selection principle predicts one choice in each period, it makes a good prediction if it has a correct prediction significantly greater than 50%. Table 3.4 reports the percentage of correct prediction for each selection principle by cohort for the incomplete information treatment and the complete information treatment, respectively.

Cohorts 1 to 8 were conducted under the incomplete information condition. No selection principle can predict the decisions perfectly, and most participants used a combination of principles. Each method was used more than 50% of the time, which means that it performed better than a random selection. The global games prediction, which is equivalent to the risk dominance criterion, has the highest correct prediction for six cohorts, excluding cohorts 2 and 3 in which the Rawlsian principle makes a slightly better prediction (but it is not significantly different from the risk dominance criterion). On average, players selected the global games choices about 71% of the time. It is surprising that the Utilitarian principle, which generates the highest payoff over time, performs much worse than risk dominance and Rawlsian. Comparing between Rawlsian and Utilitarian principles, players selected the Rawlsian choices more often (66% compared to 60%). Rawlsian makes a better prediction than Utilitarian for 6 cohorts, excluding cohorts 1 and 5. Maximax performs the worst in every cohort; the correct prediction rate is a little over 50%. This is probably because of the fact that, if every player used the maximax strategy, it is very likely that it will result in a mismatch, and each of them would earn only 100 points for that period.

Cohorts 9 to 16 were conducted under the complete information conditions. Cohort 10 is perhaps the most remarkable. More than 80% of the choices made by cohort 10's players were consistent with Rawlsian and less than 50% were consistent with the Utilitarian principle. This cohort showed a very strong tendency toward the Rawlsian principle. For other cohorts, the Utilitarian principle predicts the choices better than Rawlsian for only two cohorts, cohort 9 and cohort 14. The choices made by cohorts 9, 13 and 16 were consistent with risk dominance by more than 70% of the time.

3.5.2 Type Classification

We follow Costa-Gomes, Crawford and Broseta (2001) to conduct a maximum likelihood error-rate analysis for my participants' choices. The model is a finite mixture model in which each participant's type is drawn from a common prior distribution over three types, which are risk dominance, Utilitarian, and Rawlsian and remains constant for the whole session.[11]

Let $i = 1, ..., N$ index the participants in the treatment and let $k = 1, ..., 3$ index types. We assume that each player normally follows the predictions of a particular type, but in each game he makes an error with probability $\epsilon_k \in [0, 1]$, type k's error rate. With probability ϵ_k, a participant makes choices randomly which means he selects either A or B with probability 0.5. For a type-k participant, the probability of type k's decision is $1 - 0.5\epsilon_k$ and the probability of another decision is $0.5\epsilon_k$.

The likelihood function can be constructed as follows. Let Q^i denote the total number of games for player i that I include in my analysis.[12] Let x_k^i denote the number of games that player i makes a choice that is consistent with type k. Let p_k denote participants' common prior type probabilities where $p_1 + p_2 + p_3 = 1$, and let ϵ_k denote type k's error rate. Participant i's log-likelihood function with a particular

[11] We have tried four types including maximax type; the results suggest no player is a maximax type.

[12] We only include the games that satisfy $W_i > Y_i, Z_i > X_i > 100$ in this analysis. There are 53 games for the complete information treatment and 35 to 45 games for the incomplete information treatment.

Table 3.5: Aggregate Type Classification (Type 1 is Risk Dominance, Type 2 is Utilitarian, and Type 3 is Rawlsian).

Treatment	Incomplete	Complete
p_1	0.6648 (0.1260)	0.5256 (0.0498)
p_2	0.0894 (0.0281)	0.1085 (0.0342)
p_3	0.2458 -	0.3659 -
ϵ_1	0.5071 (0.3700)	0.5133 (0.0261)
ϵ_2	0.7845 (0.1139)	0.7214 (0.0920)
ϵ_3	0.2561 (0.1316)	0.3505 (0.0319)
N	2512	3392

sample with choice profile x^i can be written as:

$$\ln L^i(p, \epsilon|x^i) = \ln \left[\sum_{k=1}^{3} p_k \prod (1 - 0.5\epsilon_k)^{x_k^i} (0.5\epsilon_k)^{Q^i - x_k^i} \right]. \tag{3.1}$$

The aggregate log-likelihood function is given by:

$$\ln L(p, \epsilon|x) = \sum_{i=1}^{N} \ln \left[\sum_{k=1}^{3} p_k \prod (1 - 0.5\epsilon_k)^{x_k^i} (0.5\epsilon_k)^{Q^i - x_k^i} \right] \tag{3.2}$$

With three types, this model has 5 independent parameters to estimate: 2 independent type probabilities p_k[13] and 3 independent error rates ϵ_k.

Table 3.5 estimates equation (2) using maximum likelihood for incomplete information and complete information treatments separately. Under incomplete information conditions, the risk dominance type makes up two-third of the estimated type distribution. The Rawlsian type makes up one-quarter and the Utilitarian type

[13] We do not estimate p_3 as $p_3 = 1 - (p_1 + p_2)$.

makes up less than 10% of the type distribution. The results are consistent with Table 3.3 where most choices are consistent with risk dominance. Error rates are quite high which suggests that players do not follow their types consistently. This is not surprising given that the expected payoff from two equilibria are similar in many games. The Risk dominance type follows its type's action about 49% while Rawlsian type follow its type's action about 74%.

Under complete information, risk dominance type makes up about 53% of the estimated type distribution. Rawlsian makes up 37% and Utilitarian makes up a little over 10% of type distribution. The result under two conditions are similar. The main difference is I observe higher proportion of participants as risk dominance types under the incomplete information condition than the complete information condition. This suggests that incomplete information makes risk dominance or the global games solution become more salient.

3.5.3 Debriefing Questionnaire

After the 100 choices were made, the participants were asked to complete a debriefing questionnaire consisting of four questions. The first question was, "What strategy did you use while playing this game? Please include details about what led you to choose A or B." The answers were revealing. We cannot categorize many participants because their answers were not clear about the criteria they were using to make a decision. A typical answer was, "I tried to choose the answer I thought the other participant would choose." Many choices were consistent with risk dominance; however, no participant mentioned risk dominance. This is not surprising because we do not expect them to report that they select "the outcome with the larger product of the deviation losses" or "the equilibrium with the larger basin of attraction under best response dynamics" anyway.

Despite a high rate of uncategorized answers, many answers can be categorize as Rawlsian, Utilitarian, or maximax. Thirty-four percent of the participants in the incomplete information treatment and thirty-nine percent of the participants in the complete information treatment mentioned equality or maximizing the payoff of the worst-off player (Rawlsian). For example, a participant reported, "I tried to be fair and chose the outcomes that would be the most equal." Only eleven percent of the participants in the incomplete information treatment and nine percent of the participants in the complete information treatment said they selected the choice with the larger sum of the payoffs (Utilitarian). For example, a participant reported, "I would pick the highest combined number. So if choice A had a higher total than choice B when I would add up the numbers I would choose choice A." Nine percent of the participants in each treatment reported using maximax as one participant reported, "I chose the highest number on the left side of the box because that was how much I was going to earn."

The second debriefing question was, "Did you change your strategy over time?" Forty-seven percent of the participants in the incomplete information treatment and forty-four of the participants in the complete information treatment reported changing their strategy over time.

The third debriefing question question was, "If you changed your strategy, what made you change it?" The typical answer was to try to coordinate better with other players after their initial strategies did not work out well. For example, a participant reported, "I had to adapt my strategy because evidently many other people don't know how game theory works. I had to try to put myself in their shoes and think about what they were going to pick and adjust my pick accordingly. I feel that the end result would have been much better if I would have taken the uneducated route the whole time." Some participants were frustrated about other players' choices so they decided to change their strategies as one participant reported, "There were a few people in my group who would refuse to give up 10 or 20 points so that the other person could double theirs. That made me pretty frustrated, so after that I was less charitable."

The last question asked participants, "If you could play this game again, what would you do?" Forty-three percent answered that they would do the same thing. Thirty percent answered that they would begin with their strategy that they adopted at the end of the session earlier. Some participants reported that they would use a maximax strategy in every period.[14] Other frequently mentioned answers include wishing that other players would choose the choices that they expect, or they could eliminate those who play irrationally.

3.6 Conclusion

Bargaining problems usually result in multiple ways to divide a surplus. Many equilibrium selection principles have been proposed to select a unique equilibrium. However, once we introduce noise as in global games theory, only the risk-dominant criterion survives as the equilibrium selection principle. This paper tests the salience of this prediction. Therefore, I run an experiment where each subject plays a sequence of perturbed bargaining games with either complete or incomplete information. The results show that risk dominance can explain the strategies of subjects better than either Rawlsian and Utilitarian under both information conditions. Risk dominance is more salient in sessions with incomplete information than sessions with complete information which supports the global games theory.

One may be interested in whether the Rawlsian or Utilitarian principles is more salient. The results from a debriefing questionnaire reveals that more people have

[14]The typical words using for a maximax strategy were "play selfishly" or "play aggressively".

preferences toward Rawlsian than Utilitarian; more than one third of answers from subjects can be classified as the Rawlsian type, with only ten percent as the Utilitarian type. This is consistent with the real decisions in the experiment as the Rawlsian principle can explain the choices better than the Utilitarian principle under both information conditions.

The fact that risk dominance is more salient under incomplete information also suggests that players may use different strategies in games with different information conditions. The implied “social preferences” of people are different under different information conditions. Incomplete information can change people with different strategies to use similar strategies in bargaining games. One open question is what drives people under two different information conditions to play differently.

It is not easy to coordinate in my bargaining games as the results show that the miscoordination rate is very high (almost one-third under complete information and even higher under incomplete information). Testing behavior in other bargaining games, especially when it is easier to coordinate, is worth considering.

4. EQUILIBRIUM SELECTION IN GLOBAL ENTRY GAMES WITH STRATEGIC SUBSTITUTES AND COMPLEMENTS

4.1 Introduction

Previous experimental work has shown that when playing a sequence of global entry games, most subjects deviate from the global games predictions in favor of payoff dominance, i.e., they enter the market more often than theoretical predictions, see Heinemann, Nagel and Ockenfels (2004) and Cornand (2006) for example. These results were documented in an environment with strategic complements only, i.e., there is a non-decreasing function between the payoffs from entering the market and the number of firms who enter the market. Karp, Lee and Mason (2007) analyze an entry game with strategic substitutes and complements where the relationship between the payoffs from entering the market and the number of firms who enter the market is an increasing function in some regions and a decreasing function in other regions. They show that under incomplete information with certain conditions, there exists a unique threshold equilibrium in which firms enter the market when the observed fundamental value is above a certain threshold and do not enter the market otherwise. In contrast to games with incomplete information, there are multiple equilibria in games with complete information. With both strategic substitutes and complements, over-entry does not yield higher payoffs than the equilibrium strategy. This is in contrast with the usual entry games with strategic complements only, where deviating from the equilibrium strategy might yield higher payoffs.

In this chapter, I conduct an experiment where each subject plays a sequence of perturbed entry games with strategic substitutes and complements in one of two treatments: one with complete and one with incomplete information. Under com-

Table 4.1: A Class of Entry Games where $Q \in [0, 400]$

No. of choice A	0	1	2	3	4	5	6
A	Q	$Q + 50$	$Q + 100$	$Q + 200$	$Q + 100$	$Q + 50$	Q
B	300	300	300	300	300	300	300

plete information, subjects' strategies vary, which is consistent with the predictions of multiple equilibria. Under incomplete information, subjects deviate from the equilibrium, but in a different way from previous studies with entry games with strategic complements only. They enter the market less often than the theoretical prediction, which is consistent with risk-averse behavior since entering the market is risky. Thus in the absence of payoff dominance, global games can predict subjects' behavior better than when there is a payoff dominance.

The class of entry game with strategic substitutes and complements, depicted in Table 4.1, models a situation in which symmetric players have two choices: A, enter the market, and B, do not enter the market. Choosing B and staying out of the market guarantees a payoff of 300 regardless of other players' choices. If a person chooses A and enters the market, the payoff depends on Q and the number of other players who choose to enter the market, as shown in the table. An example of a game with these properties is a market with both positive network effects and congestion. In such a market, positive network effects may make it more attractive for a firm to enter a new market if few other firms also enter. However, if a large number of firms enter, the market becomes too crowded and further entry is unattractive.

Given the fact that it is more attractive to choose A when Q is high, I expect players to play "threshold" strategies where the players choose A if $Q > Q^*$ and B if $Q \leq Q^*$. However, under complete information conditions, in which all payoffs are common knowledge, using the same thresholds will not benefit players because the results will be either all or no players in the market. The payoffs are minimized in that situation; therefore, I expect different players to use different thresholds.

In contrast to games with complete information, there exists a unique threshold in games with incomplete information under certain conditions. Under incomplete informtaion, the fundamental state variable (Q) cannot be observed with certainty: each player observes an independent signal of Q. In this game, there exists a unique threshold where players enter the market when observing $Q \geq 182$. This is from the fact that, even when subjects use the same threshold, observing different signals of Q can lead to different choices. This benefits players, since the payoffs from entering are higher when about half of people enter the market.

Previous experimental research on entry games with strategic complements demonstrates that subjects deviate from the global games predictions in favor of payoff dominance; they choose A more often than theoretical predictions. Deviating from the predictions is reasonable in those games because doing so can generate higher payoffs for subjects. However, in this paper, no payoff dominance exists in games with incomplete information, and deviating from the equilibrium threshold does not yield higher payoffs as there are congestion effects. Therefore, I expect that subjects will not select A more often than the equilibrium predictions as observed in previous papers. In fact, I expect that subjects would select A less often than equilibrium because selecting A is risky.

Given different theoretical predictions, I compare a sequence of entry games with strategic substitutes and complements in two treatments: complete information and incomplete information. Under complete information treatment, subjects observe the actual value of q with certainty, while under incomplete information treatment, subjects observe the value of q with noise that is uniformly distributed with zero mean.

Our results show that under complete information, subjects use different thresholds as expected. Under incomplete information, subjects use similar thresholds but are higher than theoretical predictions. This is in contrast with entry games with strategic complements which indicates that subjects use lower thresholds than theoretical predictions. Thus my results indicate that without payoff dominance, players do not over-select risky options.

To my knowledge, this paper is the first to examine the predictions of global games theory in the entry games with strategic substitutes and complements.

In summary, this paper considers a sequence of perturbed entry games with strategic substitutes and complements in two treatments: complete information and incomplete information. There is an evidence of multiple equilibria in games with complete information. In contrast, subjects under incomplete information treatment play similar thresholds which are higher than theoretical predictions but consistent with risk-averse behavior.

4.2 Analytical Framework

Consider the entry game with strategic substitutes and complements given in Table 4.1, which is played by 7 identical players. Let i index the player. The players simultaneously choose between A, enter the market, and B, do not enter the market. The secure choice of do not enter the market, B, guarantees a payoff of 300 regardless of other players' choices. If a person chooses to enter the market, A, the payoff depends on the fundamental state variable, Q, and the number of other players who choose to enter the market. Players who choose A receive the highest payoff when 3 other players also choose A; the payoff is lower as the number of other players who choose A is further away from 3.

4.2.1 Equilibrium with Complete Information

Under complete information, there is a unique dominance solvable equilibrium when Q is less than 100, all players play B, or when Q is more than 300, all players play A. Multiple equilibria exist when $Q \in (100, 300)$. Two symmetric equilibria are the following: (1) All players choose B; (2) Each player plays a mixed strategy in which all players have the same probability of choosing A for the same value of Q. There are also many asymmetric equilibria.

When $Q < 300$, all players choosing B is a symmetric equilibrium in secure strategies. Players who choose B receive a payoff 300 regardless of all other players' choice. Three-hundred is greater than the payoff that a player would receive if she chose A, because if no other player or all other players chose A, she would receive a payoff Q which is less than 300. No player has an incentive to change the strategy because if she deviates and selects A, her payoff would be Q which is less than 300, the payoff if she chose B.

There exists strict asymmetric Nash equilibria in which 4 players choose A when $Q \in (100, 200)$, 5 players choose A when $Q \in [200, 250)$, and 6 players choose A when $Q \in [250, 300)$. Consider a case where $Q = 120$, each of 4 players who selects A receives a payoff $Q + 200 = 320$ and players who select B receive a payoff 300. Each player who selects A has no incentive to deviate to B because it results in a lower payoff of 300. Each player who selects B also has no incentive to deviate to A because it results in 5 players selecting A, which lowers their payoff to $Q+100 = 220$, less than 300 from choosing B.[1] A similar argument can be made for all the other

[1] Note that an outcome in which 1, 2, or 3 players choose A cannot be an equilibrium. Suppose that such an equilibrium existed, each person who selects A would receive a payoff at least 300 in order for him not to deviate to B. If one more player selects A when there are less than 4 As would increase the payoff for those who select A, then a person who previously chose B would want to deviate to A. Therefore, no equilibrium has 1, 2, or 3 players choosing A.

values of Q. In these asymmetric equilibria, players receive different expected payoffs. Players who select A receive a higher payoff than those who select B. The strategy coordination problem is severe in these asymmetric equilibria, because they require the right number of players to select A and B given Q and the right number of players are different for different values of Q.

Since this game is symmetric, a more accurate equilibrium prediction might be the symmetric mixed strategy equilibrium. Let p_i denote the probability that player i chooses A. In a symmetric strategy combination all players use the same mixed strategy $p_i = p$. In order for each player to play a mixed strategy, the expected payoffs from choosing A and B must be equal. For $Q \leq 181$, there is no such equilibrium since the expected payoffs from choosing A is less than 300 for any p.[2]

For $Q = 182$, there exists an equilibrium with $p = 0.53$. The value of p is higher when the value of Q is higher and it approaches 1 when Q approaches 300. This equilibrium has a monotonic relationship (an increasing function) between p and Q for $Q \in [182, 300]$.

Many experiments about global games show that many players use threshold strategies. A threshold strategy is a strategy in which players choose B when $Q < Q^*$ and choose A when $Q \geq Q^*$, and we call Q^* a threshold. From the three types of equilibria discussed above, only the first equilibrium (secure strategy) is a threshold strategy. The secure strategy has a threshold of 300. One example of a threshold strategy is maximax.[3] In this game, a player selects the choice that gives the highest possible payoff, as if all other players also act to maximize her payoff. In this game,

[2]The probability p that maximizes the expected payoff of choosing A is 0.5 for any values of Q. With $p = 0.5$, the expected payoff of choosing A is $Q + 118.75$. This payoff is higher than 300, the payoff of choosing B, when Q is greater than 181.25. So, no mixed strategy equilibrium exists when $Q \leq 181$.

[3]Van Huyck and Viriyavipart (2014) report that many subjects in their global stag hunt games experiments used a maximax strategy.

maximax consists of a threshold of 100, which is not an equilibrium.

Experimental evidence suggests that people often deviate systematically from equilibrium especially when they have no experience with the game. Stahl and Wilson (1994, 1995) and Nagel (1995) introduce a non-equilibrium model based on level-k thinking. In this model, level-0 thinkers play uniformly, level-1 thinkers best respond to a belief that everyone else is a level-0 thinker, level-2 thinkers best respond to a belief that everyone else is a level-1 thinker, and so on. In this game, level-1 players have a threshold of 182 given the belief that all other players choose randomly (level-0).[4] Level-2 players will play a threshold of 300 given the belief that all other players have a threshold of 182.[5] Because the threshold of 300 is an equilibrium, level-3 and higher level players would also play this threshold.

4.2.2 Coordination and Efficiency with Complete Information

In this game, the most efficient outcome is when 4 players choose A and 3 players choose B when $Q > 100$ and all players choose B when $Q \leq 100$. The average expected payoff per period if all players can agree on this strategy, which is not an equilibrum strategy for $Q \geq 200$, is 364.34.[6] The expected payoff from playing either a secure strategy or the symmetric mixed strategy equilibrium in which all players use the same mixed strategy $p_i = p$ is 312.59 which is about 86% of the most efficient outcome. The expected payoff from playing the pure-strategy equilibrium in which

[4]The payoff of choosing A when all other players choose A with probability 0.5 is $Q + 118.75$ for any values of Q. The best response for this believe is to choose A when Q is greater than 181.25 which is a threshold of 182. This threshold is the same threshold as the equilibrium threshold under incomplete information.

[5]When all other players use the same threshold, player i's payoff from choosing A is Q because there are either all players or no player choosing A. Therefore, the best response for this believe is a threshold of 300.

[6]If $Q \leq 100$, the payoff is 300. If $Q > 100$, players who choose A earn $Q + 200$ and players who choose B earn 300, so the average payoff is $\frac{4}{7} \times (Q + 200) + \frac{3}{7} \times 300 = \frac{4}{7}Q + 242.86$. This average over the range of $Q \in [101, 400]$ is 386. Therefore, the expected payoff over the whole range is 364.34.

Table 4.2: A Class of Global Entry Games where $Q \in [0, 400]$, $Q_i = Q + E_i$ where $E_i \in \{-120, -119, ..., 0, ..., 120\}$

No. of choice A	0	1	2	3	4	5	6
A	Q_i	$Q_i + 50$	$Q_i + 100$	$Q_i + 200$	$Q_i + 100$	$Q_i + 50$	Q_i
B	300	300	300	300	300	300	300

no player chooses A when $Q \in [0, 100]$, 4 players choose A when $Q \in (100, 200)$, 5 players choose A when $Q \in [200, 250)$, 6 players choose A when $Q \in [250, 300)$, and all players choose A when $Q \in [300, 400]$ is 324.45. This is about 89% of the most efficient outcome.

4.2.3 Equilibrium Selection with Incomplete Information

In the game with incomplete information, the fundamental state variable (Q) cannot be observed with certainty. Each player observes the incomplete information in Table 4.2 but the actual payoffs are determined by the game in Table 4.1. Similar to the game with complete information, the payoff from choosing B is 300, which dominates A if $Q_i < 100$ (the maximum expected payoff from choosing A is when 3 other players choose A, $Q + 200$ which is less than 300).

Choosing A when $Q_i > 300$ has a minimum expected payoff equals to Q_i which dominates B (when all players chose B). We can use the concept of global games to pin down a unique equilibrium threshold in which all players choose A when $Q_i \geq Q^*$ and choose B when $Q_i < Q^*$. If a player observes $Q_i = Q^*$, he knows that each other player has a 50% chance to observe $Q_j > Q^*$and chooses A; and a 50% chance to observe $Q_j < Q^*$ and chooses B. We can calculate the expected payoff of player i choosing A when observing $Q_i = Q^*$ from:

$$E\pi_A(Q^*) = \sum_{k=0}^{6} p(k) \cdot E\pi_{A,k}(Q^*),$$

where $E\pi_A(Q^*)$ is the expected payoff of choosing A when observing Q^*, $p(k)$ is the probability that k other players choose A, $E\pi_{A,k}(Q^*)$ is the expected payoff of choosing A when observing Q^* and k other players choose A. The probability that k players choose A is calculated from $p(k) = \frac{\frac{6!}{k!(6-k)!}}{2^6}$.[7] Player i's expected payoffs from choosing A when $Q_i = Q^*$ are Q^*, $Q^* + 50$, $Q^* + 100$, $Q^* + 200$, $Q^* + 100$, $Q^* + 50$, and $Q^*$for $k = 0, 1, 2, 3, 4, 5, 6$, respectively. Player i is indifferent between choosing A and B when $Q_i = 181.25$; therefore, $Q^* = 182$ which means that each player would choose A when observing $Q_i \geq 182$ and choose B when observing $Q_i < 182$.

All other thresholds cannot be constituted as a mutual best response or an equilibrium for every player in the group. For example, if all other players except player i use a threshold of 300 (a secure strategy); player i should choose A when observing $Q_i = 300$ since his expected payoff from playing A is 419 which is much higher than the payoff of 300 from choosing B. His best response threshold is 233 in this case. If all other players use a threshold less than or equal to 160, player i's best response threshold is 300. It is interesting that if all other players use a threshold between 161 and 178, player i's best response is not monotonic. For example, if the threshold is 170, player i should choose A when observing $Q_i \in [182, 258]$ and $Q_i \geq 300$ and choose B when observing $Q_i < 182$ and $Q_i \in [259, 299]$.

4.2.4 Coordination and Efficiency with Incomplete Information

Under incomplete information, the most efficient symmetric outcome is when all players use a threshold of 289. The expected payoff for each player if all players can agree on this threshold is 334.05 per period. However, this threshold is not an equilibrium. If all other players use this threshold, player i has a best response

[7] Each of 6 players has 2 choices, A and B with the same probability, so there are 2^6 possibilities. The number of possibilities that k players choose A is $6Ck$ which is the number of different, unordered combinations of k objects from a set of 6 objects. $6Ck$ can be calculated from $\frac{6!}{k!(6-k)!}$. So, the probability that k players choose A is $\frac{\frac{6!}{k!(6-k)!}}{2^6}$.

threshold of 227 in which he earns an expected payoff 343.51 per period.

An expected payoff from playing the unique equilibrium threshold of 182 is 316.85 per period. This is about 95% of the expected payoff from the most efficient threshold. Another interesting threshold is 300, a secure strategy under complete information, an expected payoff from playing this threshold is 333.70. This is about 99.9% of the expected payoff from the most efficient threshold. The best response threshold given that all other players use a threshold of 300 is 233 with the expected payoff 344.78.

4.3 Experimental Design

The stage game form used in the experiment is given in Table 4.2. The stage game was played 100 times to give adequate experience for the iterative elimination of strictly dominated strategies to convergence to equilibrium. The values of Q used in the experiment were integers in the interval 0 to 400, that is, $Q \in \{0, 1, 2, \ldots, 400\}$. The sequences of a hundred values of Q were generated by a computer using a uniform distribution. As stated in the instructions, "Many sequences of one hundred Qs were generated. One of these sequences will be used in today's session." The sequence was chosen to be representative of a uniform distribution even in small samples. The units denote fifteenths of a cent.

Two treatments were conducted. In the baseline treatment of complete information about Q, $E_i = 0$. In the incomplete information treatment, Q was only observed with error. The private signal error was $E_i \in \{-120, -119, \ldots, 119, 120\}$. The sequences were generated in the same way as the Q sequences. We used the same sequence of Q for both treatments.

The instructions were read aloud to insure the game was common information among the participants. After the instructions the participants filled out a questionnaire to establish that the participants knew how to calculate their earnings. There were always mistakes on at least one questionnaire and the section on calculating earnings was always reread to the participants.

Two sessions of three cohorts and one session of two cohorts for a total of eight cohorts were conducted for each treatment. Each cohort consisted of seven participants. Thus, each treatment used 56 participants and the total number of participants was 112. The participants were Texas A&M University undergraduates recruited campus wide using ORSEE, see Greiner (2004).

The experiment was programmed and conducted with the software z-Tree, see Fischbacher (2007). The experiment was conducted in the Economic Research Laboratory at Texas A&M University in April 2014. A five dollar show up fee plus their earnings in the session were paid to the participants in private and in cash. The average earning is about $26.14 for a session that lasted about 90 minutes.

After the decision making portion of the session was completed and while they waited for their earnings to be calculated, participants filled out a questionnaire that asked them to explain their behavior in the session.

4.4 Experimental Results

Subjects in my experiments played a sequence of 100 global entry games.[8] Section 4.3.1 reports basic results and Section 4.3.2 estimate the threshold using logit model.

4.4.1 Basic Results

A useful way to look at the data is with the frequency of A among a cohort by either the private signal, Q_i, or Q depending on whether the treatment is incomplete information or complete information. Tables 4.3 and 4.4 report the frequency for the complete information treatment for the first and the last 50 periods, respectively.

[8] 100 games used in my experiments are shown in the appendix.

Tables 4.5 and 4.6 report the frequency for the incomplete information treatment for the first and the last 50 periods, respectively.

Cohorts 1 to 8 on Tables 4.3 and 4.4 were conducted under the complete information conditions. Looking at the tables, it is clear that subjects used threshold strategies: they selected A when Q were high and B when Q were low. There were some choices that are dominated strategies, i.e., they selected A when $Q < 100$ or selected B when $Q > 300$. The proportion of people who chose dominated strategies are small and those who chose B when $Q > 300$ could be interpreted as other-regarding preferences since that would help other group members earned higher for that period. [9] In the last 50 periods, 80% of choices were A when $Q \in [250, 300)$ and less than half of choices were A when $Q \in [200, 250)$ except cohort 1 who chose A more often than other cohorts.

Cohorts 9 to 16 on Tables 4.5 and 4.6 were conducted under the incomplete information conditions. Under incomplete information, there exists a unique threshold of 182. Similar to subjects under complete information treatment, it is clear that subjects used threshold strategies: they selected A when Q_i were high and B when Q_i were low. There were some learning from the first 50 periods to the last 50 periods. When Q_i were less than 150, very few choices were A, especially in the last 50 periods. When $Q_i \in [200, 250)$, a little more than a half of choices were A; therefore, it is very clear that they had threshold strategies between 200 and 250.

4.4.2 Estimated Thresholds

The distributions in Tables 4.3 to 4.6 appear to us to have the shape of a logistic function. In order to get a more precise measure of the heterogeneity of the various cohorts, I estimated the following logit model on the cohort data for periods 76 to

[9] There was one person who reported he made choice to avoid coins, and tried to earn exactly \$25; however, he ended up getting \$25.10 since I rounded the cents up to the nearest 10-cent.

Table 4.3: A Frequency of Choice A for the First 50 Periods, by Cohort, Complete Information

Cohort\\Q	[0,50)	[50,100)	[100,150)	[150,200)	[200,250)	[250,300)	[300,350)	[350,400]
1	0.00	0.00	0.00	0.16	0.66	0.86	1.00	1.00
2	0.00	0.00	0.00	0.05	0.54	0.80	0.95	1.00
3	0.00	0.02	0.04	0.16	0.54	0.86	0.88	1.00
4	0.00	0.00	0.00	0.05	0.43	0.84	0.98	1.00
5	0.00	0.00	0.04	0.05	0.55	0.69	0.90	1.00
6	0.00	0.00	0.00	0.09	0.50	0.92	0.98	1.00
7	0.00	0.02	0.11	0.11	0.61	0.84	1.00	1.00
8	0.02	0.00	0.04	0.09	0.66	0.76	0.93	1.00

Table 4.4: A Frequency of Choice A for the Last 50 Periods, by Cohort, Complete Information

Cohort\ Q	[0,50)	[50,100)	[100,150)	[150,200)	[200,250)	[250,300)	[300,350)	[350,400]
1	0.00	0.00	0.05	0.25	0.67	0.86	1.00	1.00
2	0.00	0.00	0.00	0.00	0.43	0.86	1.00	1.00
3	0.00	0.00	0.00	0.03	0.49	0.84	0.86	0.86
4	0.00	0.00	0.00	0.03	0.30	0.86	1.00	1.00
5	0.00	0.00	0.00	0.02	0.33	0.79	0.89	1.00
6	0.00	0.00	0.02	0.00	0.36	0.86	0.96	1.00
7	0.00	0.00	0.00	0.00	0.29	0.84	1.00	1.00
8	0.05	0.00	0.00	0.00	0.66	0.82	0.86	0.78

Table 4.5: A Frequency of Choice A for the First 50 Periods, by Cohort, Incomplete Information

Cohort\ Q_i	[-120,0)	[0,50)	[50,100)	[100,150)	[150,200)	[200,250)	[250,300)	[300,350)	[350,400)	(400,520]
9	0.00	0.00	0.00	0.11	0.25	0.70	0.88	0.97	0.94	1.00
10	0.03	0.08	0.00	0.25	0.35	0.77	0.93	0.91	1.00	1.00
11	0.03	0.04	0.08	0.33	0.43	0.65	0.80	0.94	1.00	0.93
12	0.04	0.00	0.04	0.15	0.27	0.63	0.78	1.00	0.94	1.00
13	0.00	0.00	0.00	0.21	0.20	0.63	0.86	0.88	1.00	1.00
14	0.00	0.00	0.00	0.09	0.33	0.77	0.89	0.88	0.95	1.00
15	0.08	0.05	0.09	0.26	0.36	0.74	0.85	0.91	0.94	0.94
16	0.00	0.04	0.03	0.08	0.29	0.63	0.91	1.00	1.00	1.00

Table 4.6: A Frequency of Choice A for the Last 50 Periods, by Cohort, Incomplete Information

Cohort\Q_i	[-120,0)	[0,50)	[50,100)	[100,150)	[150,200)	[200,250)	[250,300)	[300,350)	[350,400)	(400,520]
9	0.00	0.00	0.00	0.02	0.25	0.70	0.93	1.00	0.96	1.00
10	0.00	0.00	0.00	0.00	0.31	0.69	0.89	1.00	0.84	1.00
11	0.00	0.00	0.00	0.08	0.19	0.57	0.73	0.93	1.00	1.00
12	0.14	0.00	0.00	0.08	0.27	0.58	0.75	0.97	1.00	1.00
13	0.00	0.00	0.00	0.05	0.20	0.57	0.85	1.00	1.00	1.00
14	0.00	0.00	0.00	0.00	0.21	0.54	0.84	1.00	1.00	1.00
15	0.00	0.00	0.00	0.02	0.20	0.75	0.79	0.94	0.96	1.00
16	0.00	0.00	0.03	0.03	0.24	0.57	0.89	0.96	1.00	1.00

Table 4.7: Estimated Logit Models and Critical Values by Cohort for Last 25 Periods

Cohort	Treatment	b_0	b_1	$Q_i = p^{-1}(0.5)$	Rank
1	Complete	-7.208	0.035	205.1	1
2	Complete	-13.523	0.058	231.8	11
3	Complete	-7.146	0.030	238.9	14
4	Complete	-12.277	0.053	230.9	10
5	Complete	-9.558	0.039	246.1	16
6	Complete	-15.842	0.067	235.6	13
7	Complete	-16.831	0.070	242.1	15
8	Complete	-5.688	0.024	234.4	12
9	Incomplete	-9.335	0.044	213.8	6
10	Incomplete	-6.659	0.031	211.9	4
11	Incomplete	-7.357	0.033	225.8	9
12	Incomplete	-5.513	0.026	212.8	5
13	Incomplete	-6.794	0.032	213.9	7
14	Incomplete	-10.752	0.049	220.7	8
15	Incomplete	-6.802	0.033	205.7	2
16	Incomplete	-6.935	0.033	211.8	3

100:

$$p(Q_i) = \frac{e^{b_0+b_1(Q_i)}}{1+e^{b_0+b_1(Q_i)}},$$

where $p(Q+E)$ is the probability of A. Table 4.7 reports the estimated parameters and the threshold for the sixteen cohorts.

While it is notable that cohort 1 has the lowest estimated threshold among all cohorts, it is the only cohort under complete information that has a low threshold. All other cohorts under complete information have higher thresholds than all cohorts under incomplete information. The Mann-Whitney test statistic indicates that two groups are significatly different (p-value = 0.02). Cohorts 2 to 8 under complete information have similar thresholds between 230 and 246 and all cohorts under incomplete information have similar threshold between 206 and 226.

4.5 Literature Review

Most of the experimental literature testing global games predictions focuses on variations of the speculative attack model of Morris and Shin (1998) or an entry game. The first test of global games predictions in the entry game was Heinemann, Nagel and Ockenfels (2004). In this game, an individual has two choices: 'attack' and 'not attack'. A player who attacks has an opportunity cost T. If a sufficient number of players choose to attack, they succeed and each of the attacking agents earns an amount Y. They assume that the number of players needed for a successful attack is a nonincreasing function in Y. In this game, if $Y < T$, the dominant strategy is 'not attack'. There exists $\bar{Y}$ such that for $Y > \bar{Y}$, the dominant strategy is 'attack'. For Y such that $T < Y < \bar{Y}$, there are two pure Nash Equilibria, all 'attack' and all 'not attack'. The value of Y varied from period to period. Undominated threshold strategies were used by 92 percent of their subjects. In private information sessions, estimated mean thresholds were close to the unique equilibrium with low assurance conditions and below the unique equilibrium with high assurance conditions. In common information sessions, estimated mean thresholds were between the thresholds of the payoff-dominant equilibrium and the global game solution. However, assuming subjects believe that other players choose to attack with a probability of $\frac{2}{3}$ for any state fit the data better. Estimated mean thresholds followed the comparative statics of the global game solution and were higher under private information than under common information. This implies that common information reduces the attack threshold and increases the prior probability of devaluation in the speculative attack game.

Kneeland (2012) classifies a restricted sample of subjects from Heinemann, Nagel and Ockenfels (2004) into level-k types[10] and an equilibrium type. She estimates that around 70% of subjects are level-k types and 30% are equilibrium types. She suggests that, "Under limited depth of reasoning, public information coordinates the beliefs of players with different depths of reasoning, increasing coordination."

Cornand (2006) has two more treatments in the speculative attack game as in Heinemann, Nagel and Ockenfels (2004). In both treatments, subjects can observe two signals. In one treatment, subjects observe both private and common signals whereas subjects in another treatment observe two common signals. She finds that in the treatment with both private and common information, subjects use the public signal as a focal point. This implies that one clear public signal can control private information beliefs from private information.

Kawagoe and Ui (2010) consider a global game with ambiguous variance of noise terms. They show in their experiment that low quality information (high variance) makes less players choose the safe action, whereas uncertainty of information quantity (ambiguous variance) makes more players choose the safe action. They suggest that providing a more precise variance of noise terms can decrease the probability of a credit crisis.

Duffy and Ochs (2012) model a speculative attack as a dynamic global game where subjects have multiple periods to decide whether to attack or not. They find little difference between static and dynamic games and suggest that assuming a speculative attack game as a static game is reasonable. In contrast, Brindisi, Celen and Hyndman (2014) observe a significant difference between static and dynamic global games in their two-person investment games. They show that endogeneous timing for making a decision in global games sufficiently improves welfare. In their experiment, a player

[10] She assumes 3 level-k types: $L1$,$L2$ and $L3$.

with optimistic beliefs about the profitability of investment invests earlier, which leads to an investment by others who would not invest otherwise. They argue, "the behavioral difference between static and dynamic global investments games is sufficiently different to justify a continued focus on behavior in dynamic games".

Shurchkov (2013) focuses on learning in a dynamic speculative attack global game. She finds that subjects act more aggressively than the theoretical predictions when faced with a high cost of attacking. In addition, the results show a high degree of learning where subjects adjust their beliefs about other subjects' behavior between the stages of the experiment.

In these papers, behavior follows the comparative static prediction of global games, but not the exact thresholds that the theory would dictate. Subjects often coordinate on thresholds different from the global games prediction in favor of payoff dominance in which they can earn more. Allowing subjects to be able to observe other subjects' behavior, as in dynamic global games, can reduce strategic risk of miscoordination, and can move thresholds toward payoff dominance threholds. In addition, the differences in behavior under common and private information are not significant which suggests low level of learning to use iterated dominance arguments in private information conditions.

4.6 Conclusion

It has been shown that in global entry games with strategic complements, subjects deviate from an equilibrium prediction in favor of payoff dominance. However, in many situations strategic substitutes may result when there is as a congestion effect. This paper considers global entry games with strategic substitutes and complements. With strategic substitutes, payoff dominance does not exist and deviating from an equilibrium prediction does not generate higher payoffs to players.

Each subject participates in either complete or incomplete information treatments. Under complete information, subjects play different strategies as expected. Under incomplete information, subjects use thresholds above the theoretical predictions. The results are different from subjects in previous research who use thresholds below the theoretical predictions. The main difference from previous literature is the absence of the payoff dominance. Without payoff dominance, subjects do not enter the market (choose a risky option) too often.

5. SUMMARY

Carlsson and van Damme (1993a) introduce a global game as a tool for equilibrium selection in games with multiple equilibria. The theory of global games converts a complete information game with multiple strict equilibria into an incomplete information game, where players only observe a noisy signal of a common state variable. This results in many cases in a unique dominance solvable equilibrium prediction.

My dissertation theoretically and experimentally examines global games in three different games: stag hunt, bargaining and entry games. In all of these games, there are multiple equilibria in games with complete information conditions; however, there is a unique equilibrium in games with incomplete information conditions.

In stag hunt games, subjects under incomplete information play similar strategies to those under complete information. Under complete information, subjects coordinate on the payoff maximizing equilibrium, as expected. Under incomplete information, subjects exhibit substantial deviations from the equilibrium prediction of global games, coordinating just as well as subjects in the complete information treatment. I argue that gains from deviating from an equilibrium can drive experimental cohorts away from the equilibrium toward an efficient alternative.

Subjects in the two other games play strategies that are closer to the global games theory when compared with subjects in the stag hunt games. In the bargaining games, around two-thirds of the subjects can be classified as the risk dominance (or global games) type using a finite-mixture model. Global games theory can predict better than alternative principles including Utilitarian and Rawlsian principles in bargaining games.

The results from global entry games with strategic substitutes and complements are substantially different from the results from global entry games with only strategic complements in previous literature. Subjects in my experiments enter the market less often than theoretical predictions, while subjects in previous studies enter the market more often than theoretical predictions. The results indicate that in the absence of payoff dominance, subjects do not select risky options too often.

In summary, global games theory can be a useful tool in selecting an equilibrium from a game with multiple equilibria under complete information. Although experimental subjects do not strictly follow the prediction of the global games theory, they follow its comparative static predictions. One alternative that could drive experimental subjects away from the prediction is payoff dominance, in which subjects could earn more from deviating from an equilibrium. Without payoff dominance, subjects plays closer to the prediction of the theory.

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APPENDIX A

GLOBAL STAG HUNT GAMES

A.1 100 Games Used in Chapter 2

Table A.1: Incomplete Information Treatment: Q and Q_i: Periods 1 to 25

Period	$(Q, Q_1, Q_2, \ldots, Q_8)$
1	(275, 260, 269, 311, 265, 230, 296, 257, 266)
2	(113, 104, 91, 108, 122, 132, 154, 67, 155)
3	(496, 537, 462, 538, 494, 513, 504, 516, 501)
4	(403, 453, 403, 388, 386, 382, 358, 410, 420)
5	(66, 67, 29, 112, 70, 38, 92, 60, 110)
6	(548, 593, 585, 540, 571, 523, 517, 587, 543)
7	(323, 346, 337, 280, 274, 340, 281, 277, 362)
8	(121, 144, 161, 145, 153, 140, 135, 171, 151)
9	(577, 570, 539, 587, 534, 563, 577, 543, 586)
10	(363, 331, 379, 383, 365, 315, 357, 372, 368)
11	(15, -22, 60, 64, -7, 32, 60, 33, 28)
12	(315, 327, 334, 356, 288, 283, 299, 357, 294)
13	(432, 424, 396, 459, 470, 413, 413, 411, 412)
14	(482, 449, 456, 492, 472, 518, 479, 506, 480)
15	(125, 83, 141, 136, 108, 141, 84, 111, 124)
16	(37, 19, -6, 87, 17, 38, -10, 3, 76)
17	(486, 523, 528, 469, 521, 468, 482, 517, 505)
18	(165, 136, 173, 158, 127, 186, 169, 212, 152)
19	(19, 58, 25, -31, 4, 5, 42, 45, 33)
20	(335, 362, 331, 315, 361, 354, 359, 297, 354)
21	(243, 283, 203, 287, 229, 201, 281, 216, 195)
22	(475, 474, 458, 474, 428, 515, 503, 466, 429)
23	(247, 204, 217, 216, 270, 234, 261, 266, 218)
24	(220, 176, 247, 200, 255, 251, 242, 253, 201)
25	(429, 391, 420, 472, 407, 412, 423, 405, 423)

Table A.2: Incomplete Information Treatment: Q and Q_i: Periods 26 to 50

Period	$(Q, Q_1, Q_2, \ldots, Q_8))$
26	(110, 111, 107, 72, 102, 160, 60, 103, 67)
27	(329, 351, 355, 296, 350, 293, 368, 281, 289)
28	(290, 272, 335, 296, 332, 293, 299, 254, 328)
29	(502, 490, 466, 482, 485, 548, 540, 473, 523)
30	(15, -25, 37, 38, 57, 59, -30, 53, 43)
31	(106, 106, 131, 107, 131, 132, 70, 102, 86)
32	(402, 413, 402, 360, 423, 361, 402, 362, 381)
33	(55, 89, 85, 5, 95, 43, 7, 61, 30)
34	(596, 616, 602, 582, 613, 566, 582, 594, 563)
35	(4, -9, 4, -42, -5, 16, 14, 27, 28)
36	(484, 502, 470, 437, 450, 453, 485, 510, 473)
37	(56, 42, 9, 25, 57, 95, 84, 45, 43)
38	(282, 277, 328, 268, 290, 332, 240, 316, 318)
39	(230, 204, 261, 203, 252, 229, 217, 183, 274)
40	(426, 434, 439, 454, 422, 459, 440, 394, 467)
41	(39, 63, 16, 1, -9, 10, 7, 78, 11)
42	(253, 277, 227, 225, 263, 280, 242, 236, 206)
43	(74, 66, 108, 106, 117, 94, 87, 78, 63)
44	(325, 282, 348, 322, 307, 278, 375, 345, 350)
45	(117, 158, 74, 138, 141, 160, 112, 79, 123)
46	(399, 414, 360, 365, 390, 388, 362, 426, 449)
47	(308, 344, 280, 354, 310, 303, 349, 304, 352)
48	(255, 236, 290, 212, 228, 207, 245, 234, 272)
49	(571, 558, 612, 553, 575, 521, 603, 613, 587)
50	(174, 136, 139, 138, 213, 142, 186, 202, 144)

Table A.3: Incomplete Information Treatment: Q and Q_i: Periods 51 to 75

Period	$(Q, Q_1, Q_2, \ldots, Q_8)$
51	(329, 379, 303, 374, 314, 304, 328, 305, 317)
52	(236, 208, 236, 277, 255, 215, 235, 239, 240)
53	(544, 511, 524, 555, 555, 575, 519, 494, 502)
54	(92, 140, 54, 100, 123, 51, 65, 53, 60)
55	(463, 426, 465, 508, 504, 448, 456, 504, 462)
56	(259, 209, 291, 277, 242, 213, 271, 234, 250)
57	(397, 404, 418, 415, 362, 438, 404, 440, 347)
58	(497, 500, 451, 452, 472, 494, 503, 472, 453)
59	(455, 458, 480, 420, 438, 497, 448, 414, 488)
60	(119, 111, 75, 156, 117, 96, 82, 123, 107)
61	(576, 543, 619, 547, 601, 566, 597, 569, 549)
62	(477, 503, 503, 519, 479, 491, 481, 527, 478)
63	(46, 67, 85, 69, 88, 32, 87, 50, 22)
64	(169, 149, 152, 196, 124, 146, 166, 206, 219)
65	(204, 161, 176, 170, 173, 209, 231, 246, 162)
66	(225, 262, 241, 187, 242, 249, 175, 177, 232)
67	(513, 549, 552, 477, 546, 517, 557, 552, 483)
68	(5, 31, -1, 11, -42, 43, 2, 39, -34)
69	(420, 385, 414, 386, 385, 419, 416, 412, 397)
70	(47, 42, 75, 41, 34, 17, 30, 82, 57)
71	(307, 274, 292, 324, 356, 320, 310, 326, 324)
72	(551, 572, 519, 591, 559, 504, 534, 583, 594)
73	(576, 543, 589, 587, 526, 614, 538, 578, 580)
74	(158, 123, 172, 190, 195, 132, 172, 135, 117)
75	(87, 92, 90, 48, 129, 118, 119, 73, 48)

Table A.4: Incomplete Information Treatment: Q and Q_i: Periods 76 to 100

Period	$(Q, Q_1, Q_2, \ldots, Q_8))$
76	(412, 437, 455, 422, 412, 417, 380, 409, 375)
77	(433, 408, 383, 412, 464, 460, 468, 483, 404)
78	(180, 160, 168, 199, 155, 152, 148, 180, 130)
79	(591, 567, 626, 557, 594, 568, 603, 638, 609)
80	(370, 345, 344, 378, 408, 371, 354, 367, 375)
81	(600, 594, 642, 628, 609, 583, 622, 566, 571)
82	(192, 189, 189, 215, 185, 242, 240, 184, 222)
83	(337, 371, 324, 292, 356, 318, 371, 370, 364)
84	(116, 121, 101, 98, 163, 79, 139, 148, 68)
85	(361, 404, 358, 338, 342, 334, 398, 363, 401)
86	(342, 322, 351, 387, 308, 380, 388, 351, 390)
87	(550, 573, 510, 501, 510, 569, 576, 521, 511)
88	(51, 70, 76, 24, 55, 14, 24, 66, 73)
89	(582, 602, 595, 604, 586, 616, 540, 563, 585)
90	(309, 342, 288, 344, 276, 291, 324, 273, 296)
91	(508, 480, 533, 540, 495, 536, 506, 504, 523)
92	(157, 161, 192, 129, 199, 131, 185, 191, 171)
93	(367, 412, 375, 334, 358, 364, 412, 375, 378)
94	(201, 158, 201, 154, 233, 216, 228, 178, 199)
95	(143, 121, 112, 161, 121, 115, 132, 109, 141)
96	(224, 243, 196, 250, 260, 272, 176, 265, 258)
97	(502, 550, 464, 494, 529, 487, 472, 540, 549)
98	(211, 236, 209, 186, 189, 252, 259, 210, 229)
99	(287, 322, 321, 272, 243, 241, 265, 268, 333)
100	(319, 281, 294, 349, 275, 321, 272, 294, 290)

Table A.5: Complete Information Treatment: Q: Periods 1 to 50

Period	Q	Period	Q
1	433	26	192
2	255	27	596
3	329	28	165
4	600	29	180
5	224	30	402
6	577	31	370
7	174	32	397
8	484	33	259
9	46	34	113
10	19	35	230
11	287	36	117
12	66	37	403
13	121	38	551
14	106	39	236
15	582	40	247
16	591	41	497
17	550	42	275
18	169	43	367
19	315	44	432
20	39	45	204
21	158	46	329
22	225	47	477
23	576	48	496
24	290	49	92
25	426	50	342

Table A.6: Complete Information Treatment: Q: Periods 51 to 100

Period	Q	Period	Q
51	37	76	319
52	110	77	15
53	420	78	363
54	87	79	116
55	143	80	548
56	325	81	399
57	220	82	571
58	4	83	15
59	119	84	337
60	544	85	51
61	308	86	508
62	5	87	429
63	125	88	74
64	513	89	307
65	243	90	502
66	455	91	576
67	282	92	482
68	335	93	47
69	253	94	486
70	309	95	502
71	412	96	55
72	361	97	323
73	157	98	475
74	56	99	211
75	201	100	463

Table A.7: Chapter 2 Instructions-Complete Information

	A	B
A	500,500	$100, Q$
B	$Q, 100$	Q, Q

A.2 Instructions

A.2.1 Complete Information Treatment

Instructions

This session consists of one hundred separate decision making periods. You will participate in a group of eight people. At the beginning of period one, each of the participants in this room will be randomly assigned to a group of size eight and will remain in the same group for the entire one hundred decision making periods of the experiment. Hence, you will remain grouped with the same seven other participants for the next one hundred periods.

At the beginning of each period, you and all other participants will choose an action. An earnings table (on the next page) is provided which tells you the earnings you receive given the action you and all other participants chose. The actions you may choose are row A or row B. During a period everyone will have the same earnings table.

Your earnings are located in each cell. Units are twentieths of a cent. Your choice will be matched with the choices of the other participants in your group. You will receive the average of these earnings. The following table lists your choices A and B in the rows, and other participants in your group's choices in the columns.

Table

You have 2 choices, A and B, for all 100 periods. If you chose A and 5 other participants chose A and 2 chose B, then you would earn $(500{*}5 + 100{*}2)/7 = 385.71$

points or 19.29 cents. If you chose A and 2 other participants chose A and 5 chose B, then you would earn (500*2 + 100*5)/7 = 214.29 points or 10.71 cents. You will always receive Q points or Q/20 cents if you chose B.

What is Q?

When you choose B, your earning is Q. Q is an integer between 0 and 600 randomly determined by the computer. That means any number between 0 and 600 is equally likely to be picked by the computer.

One hundred values of Q have been generated by a computer. Many sequences of one hundred Qs were generated. One of these sequences will be used in today's session. All participants in the session will have the same value of Q in each period.

Making a choice

Making a choice consists of clicking on the button representing the row of your choice, which changes the numbers (in the table) to green and activates a confirmation button below the earnings table. You may either confirm your choice or change it by clicking on the button representing the other row. Your choice is not final until you have clicked on the confirm button.

After you have made a choice, a "please wait" message will be displayed and then the outcome will be reported.

Summary

*** The experiment consists of one hundred separate decision making periods.

*** You have been randomly assigned to a group of size eight and will remain in the same group for the entire one hundred decision making periods of the experiment.

*** You make a choice by clicking on a button, which changes the numbers to green. You must also confirm your choice by clicking on the 'confirm' button.

*** Each period, if you choose A, your choice will be matched with all of the other choices and your earnings will be the average outcome. If you choose B, you will earn Q as explained before.

*** Your balance at the end of the session will be paid to you in private and in cash.

Table A.8: Chapter 2 Instructions-Incomplete Information

	A	B
A	500,500	$100, Q$
B	$Q, 100$	Q, Q

A.2.2 Incomplete Information Treatment

Instructions

This session consists of one hundred separate decision making periods. You will participate in a group of eight people. At the beginning of period one, each of the participants in this room will be randomly assigned to a group of size eight and will remain in the same group for the entire one hundred decision making periods of the experiment. Hence, you will remain grouped with the same seven other participants for the next one hundred periods.

At the beginning of each period, you and all other participants will choose an action. An earnings table (on the next page) is provided which tells you the earnings you receive given the action you and all other participants chose. The actions you may choose are row A or row B. During a period everyone will have a private estimate of the same earnings table.

Your earnings are located in each cell. Units are twentieths of a cent. Your choice will be matched with the choices of the other participants in your group. You will receive the average of these earnings. The following table lists your choices A and B in the rows, and other participants in your group's choices in the columns.

Table

You have 2 choices, A and B, for all 100 periods. If you chose A and 5 other participants chose A and 2 chose B, then you would earn $(500*5 + 100*2)/7 = 385.71$ points or 19.29 cents. If you chose A and 2 other participants chose A and 5 chose

B, then you would earn (500*2 + 100*5)/7 = 214.29 points or 10.71 cents. You will always receive Q points or Q/20 cents if you chose B.

What is Q?

When you choose B, your earning is Q. Q is an integer between 0 and 600 randomly determined by the computer. That means any number between 0 and 600 is equally likely to be picked by the computer.

One hundred values of Q have been generated by a computer. Many sequences of one hundred Qs were generated. One of these sequences will be used in today's session. All participants in the session will have the same value of Q in each period.

Before you make a decision you will not be told what Q is but instead you will receive an estimate of Q, which we will denote by E. Let's be more precise. After the computer randomly determines Q, it also picks a random integer between Q - 50 and Q + 50. This is your estimate E. Any number between Q - 50 and Q + 50 is equally likely to be picked by the computer. Although E does not tell you what Q is exactly, it gives an estimate of it. For example if you receive an estimate E = 406, then you know that Q is not less than 406 - 50 = 356 and it is not more than 406 + 50 = 456.

Note that although Q will be the same for you and the other participants, your estimates can be different. That is, for the same Q, the computer also randomly picks other estimates exactly in the same manner for all other participants. All of these estimates are chosen independently. Therefore, it is very likely that they will be different numbers; however, all estimates will be between Q - 50 and Q +50.

Making a choice

Making a choice consists of clicking on the button representing the row of your choice, which changes the numbers (in the table) to green and activates a confirmation button below the earnings table. You may either confirm your choice or change it by clicking on the button representing the other row. Your choice is not final until you have clicked on the confirm button.

After you have made a choice, a "please wait" message will be displayed and then the outcome will be reported.

Summary

*** The experiment consists of one hundred separate decision making periods.

*** You have been randomly assigned to a group of size eight and will remain in the same group for the entire one hundred decision making periods of the experiment.

*** You make a choice by clicking on a button, which changes the numbers to green. You must also confirm your choice by clicking on the 'confirm' button.

*** Each period, if you choose A, your choice will be matched with all of the other choices and your earnings will be the average outcome. If you choose B, you will earn Q as explained before.

*** Your balance at the end of the session will be paid to you in private and in cash.

APPENDIX B

GLOBAL BARGAINING GAMES

B.1 100 Games Used in Chapter 3

Table B.1: Values of W, X, Y, Z: Periods 1 to 25

Period	W	X	Y	Z
1	416	403	506	122
2	167	581	388	507
3	45	448	349	123
4	403	117	514	2
5	291	483	312	480
6	309	117	571	102
7	568	47	423	242
8	108	293	522	85
9	41	232	344	5
10	283	169	39	423
11	383	466	277	595
12	236	234	496	101
13	186	88	414	6
14	307	494	201	590
15	349	426	447	204
16	457	378	479	362
17	496	463	588	425
18	124	203	125	182
19	320	93	481	67
20	424	36	0	547
21	581	88	214	139
22	181	366	317	356
23	492	180	275	182
24	389	6	112	18
25	560	201	206	328

Table B.2: Values of W, X, Y, Z: Periods 26 to 50

Period	W	X	Y	Z
26	278	383	578	224
27	41	490	128	135
28	386	40	119	235
29	391	451	577	73
30	126	219	9	540
31	195	138	559	49
32	307	331	562	295
33	120	288	213	189
34	314	321	283	445
35	279	180	517	74
36	116	564	143	158
37	158	591	478	178
38	575	268	369	420
39	278	267	366	213
40	403	251	242	590
41	224	525	482	406
42	352	397	26	534
43	299	515	583	136
44	264	163	554	100
45	138	292	40	296
46	78	587	268	387
47	299	426	266	490
48	45	271	236	260
49	25	338	319	251
50	98	472	167	463

Table B.3: Values of W, X, Y, Z: Periods 51 to 75

Period	W	X	Y	Z
51	81	405	565	14
52	7	483	196	61
53	519	390	538	327
54	202	468	389	331
55	107	423	282	262
56	35	246	61	96
57	325	356	570	222
58	270	482	197	564
59	81	481	477	206
60	566	49	547	363
61	506	181	505	498
62	279	345	46	468
63	12	302	56	58
64	81	451	541	35
65	28	588	541	77
66	232	481	246	368
67	1	345	333	141
68	297	288	556	90
69	100	408	345	302
70	294	128	377	73
71	450	20	247	86
72	172	199	478	121
73	503	262	282	425
74	466	139	361	457
75	511	458	66	554

Table B.4: Values of W, X, Y, Z: Periods 76 to 100

Period	W	X	Y	Z
76	290	537	338	430
77	461	142	179	175
78	540	115	317	160
79	531	117	210	448
80	429	426	528	378
81	166	556	291	215
82	147	562	327	432
83	437	289	569	134
84	429	600	504	460
85	185	369	287	337
86	209	292	507	77
87	582	211	333	213
88	537	19	199	515
89	592	103	129	259
90	512	34	97	218
91	435	1	278	221
92	504	83	159	135
93	88	238	165	133
94	387	210	156	506
95	508	263	335	381
96	348	356	63	485
97	439	105	131	369
98	144	326	101	545
99	565	10	259	563
100	249	555	271	408

Table B.5: Chapter 3 Instructions-Complete Information

	A	B
A	W, X	100, 100
B	100, 100	Y, Z

B.2 Instructions

B.2.1 Complete Information Treatment

Instructions

This session consists of one hundred separate decision making periods. You will participate in a group of eight people. At the beginning of period one, each of the participants in this room will be randomly assigned to a group of size eight and will remain in the same group for the entire one hundred decision making periods of the experiment. Hence, you will remain grouped with the same seven other participants for the next one hundred periods.

In each period, you will be randomly matched with one of the other participants in your group. At the beginning of each period, you and your counterpart will observe an earnings table (on the next page) which tells you the earnings you and your counterpart receive given the actions you and your counterpart chose. The actions you may choose are row A or row B. During a period everyone will have a private estimate of the same earnings table.

Table

You will have 2 choices, A and B, for all 100 periods. The table lists your choices in the rows, and your counterpart's choices in the columns. Your choice will be matched with your counterpart. Your earnings, in black, are located on the left of each cell while your counterparts earnings, in blue, are located on the right. Units are fifteenths of a cent.

Table B.6: Chapter 3 Instructions-Complete Information-Example

	A	B
A	$360, 240$	$100,\ 100$
B	$100,\ 100$	$300, 300$

In each period, there are 4 possible outcomes:

1) If you chose A and your counterpart chose A, then you would earn W points or W/12 cents and your counterpart would earn X points or X/12 cents.

2) If you chose A and your counterpart chose B, then each of you would earn 100 points or $100/12 = 8.33$ cents.

3) If you chose B and your counterpart chose A, then each of you would earn 100 points or $100/12 = 8.33$ cents.

4) If you chose B and your counterpart chose B, then you would earn Y points or Y/12 cents and your counterpart would earn Z points or Z/12 cents.

What are W, X, Y, Z?

W, X, Y, and Z are integers between 0 and 600 randomly determined by the computer. One hundred values for each of W, X, Y, and Z have been generated by a computer. Many sequences of them were generated. One of these sequences will be used in today's session. All participants in the session will have the same selected sequence for each of W, X, Y, and Z.

Example

For example, suppose you observe the earning table as shown above. There are 4 possible outcomes:

1) If you chose A and your counterpart chose A, then you would earn 360 points or 30 cents and your counterpart would earn 240 points or 20 cents.

2) If you chose A and your counterpart chose B, then each of you would earn 100

points or 8.33 cents.

3) If you chose B and your counterpart chose A, then each of you would earn 100 points or 8.33 cents.

4) If you chose B and your counterpart chose B, then you would earn 300 points or 25 cents and your counterpart would earn 300 points or 25 cents.

Making a choice

Making a choice consists of clicking on the button representing the row of your choice, which changes the numbers (in the table) to green and activates a confirmation button below the earnings table. You may either confirm your choice or change it by clicking on the button representing the other row. Your choice is not final until you have clicked on the confirm button.

After you have made a choice, a "please wait" message will be displayed and then the outcome will be reported.

Summary

*** The experiment consists of one hundred separate decision making periods.

*** You have been randomly assigned to a group of size eight and will remain in the same group for the entire one hundred decision making periods of the experiment.

*** You make a choice by clicking on a button, which changes the numbers to green. You must also confirm your choice by clicking on the 'confirm' button.

*** Each period, your choice will be randomly matched with one participants choice in your group. In each cell of the earnings table, your earnings are shown on the left and your counterparts earnings are shown on the right.

*** Your balance at the end of the session will be paid to you in private and in cash.

Table B.7: Chapter 3 Instructions-InComplete Information

	A	B
A	W, X	100, 100
B	100, 100	Y, Z

B.2.2 Incomplete Information Treatment

Instructions

This session consists of one hundred separate decision making periods. You will participate in a group of eight people. At the beginning of period one, each of the participants in this room will be randomly assigned to a group of size eight and will remain in the same group for the entire one hundred decision making periods of the experiment. Hence, you will remain grouped with the same seven other participants for the next one hundred periods.

In each period, you will be randomly matched with one of the other participants in your group. At the beginning of each period, you and your counterpart will observe an earnings table (on the next page) which tells you the earnings you and your counterpart receive given the actions you and your counterpart chose. The actions you may choose are row A or row B. During a period everyone will have a private estimate of the same earnings table.

Table

You will have 2 choices, A and B, for all 100 periods. The table lists your choices in the rows, and your counterpart's choices in the columns. Your choice will be matched with your counterpart. Your earnings, in black, are located on the left of each cell while your counterparts earnings, in blue, are located on the right. Units are fifteenths of a cent.

In each period, there are 4 possible outcomes:

1) If you chose A and your counterpart chose A, then you would earn W points or W/12 cents and your counterpart would earn X points or X/12 cents.

2) If you chose A and your counterpart chose B, then each of you would earn 100 points or 100/12 = 8.33 cents.

3) If you chose B and your counterpart chose A, then each of you would earn 100 points or 100/12 = 8.33 cents.

4) If you chose B and your counterpart chose B, then you would earn Y points or Y/12 cents and your counterpart would earn Z points or Z/12 cents.

What are W, X, Y, Z?

W, X, Y, and Z are integers between 0 and 600 randomly determined by the computer. One hundred values for each of W, X, Y, and Z have been generated by a computer. Many sequences of them were generated. One of these sequences will be used in today's session. All participants in the session will have the same selected sequence for each of W, X, Y, and Z.

Before you make a decision you will not be told what W, X, Y, and Z are but instead you will receive estimates of them. Let's be more precise. After the computer randomly determines W, it also picks a random integer (w) between W - 50 and W + 50. This is your w. Any number between W - 50 and W + 50 is equally likely to be picked by the computer. Although w does not tell you what W is exactly, it gives an estimate of it. For example if you receive an estimate w = 406, then you know that W is not less than 406 - 50 = 356 and it is not more than 406 + 50 = 456. Similarly, you will observe x, y, and z as estimates of X, Y, and Z in the same manner to w in each period. You will also see the range of possible values of W, X, Y, and Z in the earnings table.

Although W, X, Y, and Z will be the same for you and your counterpart, your estimates can be different. That is, for the same W (this also true for X, Y, and Z),

Table B.8: Chapter 3 Instructions-Incomplete Information-Example

	A	B
A	$400, 200$	$100,\ 100$
B	$100,\ 100$	$270, 320$

	A	B
A	$360, 240$	$100,\ 100$
B	$100,\ 100$	$300, 300$

the computer also randomly picks other estimates exactly in the same manner for all other participants. All of these estimates are chosen independently. Therefore, it is very likely that they will be different numbers; however, all estimates will be between W - 50 and W + 50.

Example

For example, suppose you observe the earning table as shown above. There are 4 possible outcomes:

1) If you chose A and your counterpart chose A, then you would earn 360 points or 30 cents and your counterpart would earn 240 points or 20 cents.

2) If you chose A and your counterpart chose B, then each of you would earn 100 points or 8.33 cents.

3) If you chose B and your counterpart chose A, then each of you would earn 100 points or 8.33 cents.

4) If you chose B and your counterpart chose B, then you would earn 300 points or 25 cents and your counterpart would earn 300 points or 25 cents.

Making a choice

Making a choice consists of clicking on the button representing the row of your choice, which changes the numbers (in the table) to green and activates a confirmation button below the earnings table. You may either confirm your choice or change it by clicking on the button representing the other row. Your choice is not final until you have clicked on the confirm button.

After you have made a choice, a "please wait" message will be displayed and then the outcome will be reported.

Summary

*** The experiment consists of one hundred separate decision making periods.

*** You have been randomly assigned to a group of size eight and will remain in the same group for the entire one hundred decision making periods of the experiment.

*** You make a choice by clicking on a button, which changes the numbers to green. You must also confirm your choice by clicking on the 'confirm' button.

*** Each period, your choice will be randomly matched with one participants choice in your group. In each cell of the earnings table, your earnings are shown on the left and your counterparts earnings are shown on the right.

*** Your balance at the end of the session will be paid to you in private and in cash.

APPENDIX C

GLOBAL ENTRY GAMES WITH STRATEGIC SUBSTITUTES AND COMPLEMENTS

C.1 100 Games Used in Chapter 4

Table C.1: Value of Q: Periods 1 to 50

Period	Q	Period	Q
1	255	26	165
2	172	27	21
3	273	28	84
4	57	29	154
5	239	30	262
6	8	31	30
7	152	32	277
8	316	33	205
9	128	34	171
10	320	35	7
11	132	36	230
12	95	37	299
13	167	38	36
14	240	39	369
15	199	40	208
16	4	41	93
17	398	42	152
18	323	43	45
19	24	44	308
20	321	45	287
21	241	46	200
22	287	47	80
23	58	48	302
24	290	49	92
25	426	50	342

Table C.2: Value of Q: Periods 51 to 100

Period	Q	Period	Q
51	245	76	180
52	256	77	354
53	117	78	175
54	35	79	231
55	398	80	202
56	185	81	121
57	233	82	26
58	295	83	358
59	326	84	235
60	112	85	306
61	213	86	157
62	139	87	341
63	367	88	287
64	265	89	62
65	373	90	264
66	278	91	99
67	400	92	356
68	126	93	86
69	294	94	209
70	173	95	186
71	347	96	251
72	202	97	171
73	124	98	38
74	192	99	212
75	206	100	177

Table C.3: Chapter 4 Instructions-Complete Information

No. of choice A	0	1	2	3	4	5	6
A	Q	$Q+50$	$Q+100$	$Q+200$	$Q+100$	$Q+50$	Q
B	300	300	300	300	300	300	300

C.2 Instructions

Instructions

This session consists of one hundred separate decision making periods. You will participate in a group of seven people. At the beginning of period one, each of the participants in this room will be randomly assigned to a group of size seven and will remain in the same group for the entire one hundred decision making periods of the experiment. Hence, you will remain grouped with the same six other participants for the next one hundred periods.

In each period, you and all other participants will choose an action. An earnings table (on the next page) is provided which tells you the earnings you receive given the action you and all other participants in your group in that period chose. The actions you may choose are row A or row B. During a period everyone will have a private estimate of the same earnings table.

Table

Your earnings are located in each cell. Units are fifteenths of a cent. You have 2 choices, A and B, for all 100 periods. If you chose A and no other participant chose A, then you would earn Q points. If you chose A and 1 other participant chose A, then you would earn Q+50 points. If you chose A and 2 other participants chose A, then you would earn Q+100 points. If you chose A and 3 other participants chose A, then you would earn Q+200 points. If you chose A and 4 other participants chose A, then you would earn Q+100 points. If you chose A and 5 other participants chose

A, then you would earn Q+50 points. If you chose A and 6 other participants chose A, then you would earn Q points. If you chose B, you will earn 300 points regardless of what the other six participants in your group chose.

What is Q?

When you choose A, your earning is between Q and Q+200 depending on the number of other participants in your group who chose A. Q is an integer between 0 and 400 randomly determined by the computer. That means any number between 0 and 400 is equally likely to be picked by the computer.

One hundred values of Q have been generated by a computer. Many sequences of one hundred Qs were generated. One of these sequences will be used in today's session. All participants in the session will have the same value of Q in each period.

Making a choice

Making a choice consists of clicking on the button representing the row of your choice, which changes the numbers (in the table) to green and activates a confirmation button below the earnings table. You may either confirm your choice or change it by clicking on the button representing the other row. Your choice is not final until you have clicked on the confirm button.

After you have made a choice, a "please wait" message will be displayed and then the outcome will be reported.

Summary

*** The experiment consists of one hundred separate decision making periods.

*** You have been randomly assigned to a group of size eight and will remain in the same group for the entire one hundred decision making periods of the experiment.

*** You make a choice by clicking on a button, which changes the numbers to green. You must also confirm your choice by clicking on the 'confirm' button.

*** In each period, if you choose A, you will earn between Q and Q+200 depending on the number of other participants in your group who chose A as explained before.

*** In each period, if you choose B, you will earn 300 points.

*** Your balance at the end of the session will be paid to you in private and in cash and the exchange rate is 1,500 experimental points for a dollar.

Table C.4: Chapter 4 Instructions-Incomplete Information

No. of choice A	0	1	2	3	4	5	6
A	Q	$Q+50$	$Q+100$	$Q+200$	$Q+100$	$Q+50$	Q
B	300	300	300	300	300	300	300

C.2.1 Incomplete Information Treatment

Instructions

This session consists of one hundred separate decision making periods. You will participate in a group of seven people. At the beginning of period one, each of the participants in this room will be randomly assigned to a group of size seven and will remain in the same group for the entire one hundred decision making periods of the experiment. Hence, you will remain grouped with the same six other participants for the next one hundred periods.

In each period, you and all other participants will choose an action. An earnings table (on the next page) is provided which tells you the earnings you receive given the action you and all other participants in your group in that period chose. The actions you may choose are row A or row B. During a period everyone will have a private estimate of the same earnings table.

Table

Your earnings are located in each cell. Units are fifteenths of a cent. You have 2 choices, A and B, for all 100 periods. If you chose A and no other participant chose A, then you would earn Q points. If you chose A and 1 other participant chose A, then you would earn Q+50 points. If you chose A and 2 other participants chose A, then you would earn Q+100 points. If you chose A and 3 other participants chose A, then you would earn Q+200 points. If you chose A and 4 other participants chose A, then you would earn Q+100 points. If you chose A and 5 other participants chose

Table C.5: Chapter 4 Instructions-Incomplete Information-Estimated Earnings Table

No. of choice A	0	1	2	3	4	5	6
A	E	$E+50$	$E+100$	$E+200$	$E+100$	$E+50$	E
B	300	300	300	300	300	300	300

A, then you would earn Q+50 points. If you chose A and 6 other participants chose A, then you would earn Q points. If you chose B, you will earn 300 points regardless of what the other six participants in your group chose.

What is Q?

When you choose A, your earning is between Q and Q+200 depending on the number of other participants in your group who chose A. Q is an integer between 0 and 400 randomly determined by the computer. That means any number between 0 and 400 is equally likely to be picked by the computer.

One hundred values of Q have been generated by a computer. Many sequences of one hundred Qs were generated. One of these sequences will be used in today's session. All participants in the session will have the same value of Q in each period.

Estimate earnings table

Before you make a decision you will not be told what Q is but instead you will receive an estimate of Q, which we will denote by E. Let's be more precise. After the computer randomly determines Q, it also picks a random integer between Q - 120 and Q + 120. This is your estimate E. Any number between Q - 120 and Q + 120 is equally likely to be picked by the computer. Although E does not tell you what Q is exactly, it gives an estimate of it. For example if you receive an estimate E = 206, then you know that Q is not less than 206 - 120 = 86 and it is not more than 206 + 120 = 326.

Note that although Q will be the same for you and the other participants, your estimates can be different. That is, for the same Q, the computer also randomly picks other estimates exactly in the same manner for all other participants. All of these estimates are chosen independently. Therefore, it is very likely that they will be different numbers; however, all estimates will be between Q - 120 and Q +120.

Making a choice

Making a choice consists of clicking on the button representing the row of your choice, which changes the numbers (in the table) to green and activates a confirmation button below the earnings table. You may either confirm your choice or change it by clicking on the button representing the other row. Your choice is not final until you have clicked on the confirm button.

After you have made a choice, a "please wait" message will be displayed and then the outcome will be reported.

Summary

*** The experiment consists of one hundred separate decision making periods.

*** You have been randomly assigned to a group of size eight and will remain in the same group for the entire one hundred decision making periods of the experiment.

*** You make a choice by clicking on a button, which changes the numbers to green. You must also confirm your choice by clicking on the 'confirm' button.

*** In each period, if you choose A, you will earn between Q and Q+200 depending on the number of other participants in your group who chose A as explained before.

*** In each period, if you choose B, you will earn 300 points.

*** Your balance at the end of the session will be paid to you in private and in cash and the exchange rate is 1,500 experimental points for a dollar.