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Abstract

We experimentally study optional costly communication in Stag-Hunt games. Prior research demonstrates that efficient coordination is difficult without a communication option but obtains regularly with mandatory costless pre-play messages. We find that even small communication costs dramatically reduce message use when communication is optional, but efficient coordination can occur with similar frequency as under costless communication. These findings can be accounted for by formalizations of forward induction that take Nash equilibrium as a reference point (such as Kohlberg and Mertens (1986) and Govindan and Wilson (2009)), while formalizations that only appeal to (higher-order) knowledge of rationality remain silent in this environment.

Keywords: coordination, communication, forward induction, experiment, stag hunt.

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I. Introduction

We study pre-play communication in Stag-Hunt coordination games in which subjects decide whether or not to send messages and, in some cases, incur a cost for sending a message. In this environment one may be concerned that agents refrain from communicating and attempt to free ride on the communication of others. In that case, outcomes might prevail that would result if communication were impossible. This would cast doubt on the relevance and external validity of the numerous demonstrations that cheap talk can significantly improve the outcomes of strategic interactions (Cooper, et al., 1992; Charness, 2000; Blume and Ortmann, 2007). A priori, it is also possible, however, that for sufficiently small costs communication would proceed unimpeded with similar effects as those from cheap talk. Our experimental findings support a third possibility: moderate communication costs do dramatically reduce message use, but without noticeable effects on efficiency relative to when communication is widespread. This suggests that the option to communicate can be as valuable as communication itself.

Our paper makes three contributions. First, it introduces a novel experimental design; prior to playing a Stag-Hunt game *all players are given access to an optional costly communication opportunity*. Second, it demonstrates that the modal behavior with optional costly communication is *efficient play without message use*. Third, the paper uses these experimental findings to differentiate among formalizations of forward induction, the notion that players rationalize their opponents' past behavior; *the central tendency in our data can be accounted for by formalizations that take Nash equilibrium as a reference point* (such as Kohlberg and Mertens (1966) and Govindan and Wilson (2009)), while formalizations that only appeal to (higher-order) knowledge of rationality remain silent in our game. Next, we discuss these three contributions in greater detail and relate them to the literature.

As a benchmark, we replicate the relevant no-communication results from the experimental literature on risk-efficiency tradeoffs in games. This literature has primarily focused on 2-player, 2-action Stag-Hunt games and their multi-player multi-action relatives, Weak-Link games.[1] In Weak-Link games there is a strong tendency for efficient play to unravel toward players choosing secure and inefficient strategies (Van Huyck et al., 1990). For the Stag-

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[1] Weak-Link games have been experimentally studied by, for example, Van Huyck et al. (1990), Weber et al. (2001), Weber (2006) and Brandts and Cooper (2006) and represent useful models of varied economic activity, such as investment or production under complementarities (Bryant, 1983; Hirschleifer, 1983; Knez and Camerer, 1994).

Hunt game, a stylized fact that emerges from the literature is that the risk-dominant outcome (Harsanyi and Selten, 1988) tends to be selected (Cooper et al., 1990 & 1992a); our replication provides further support.

A number of theoretical papers have made the case for cheap-talk messages playing a role in equilibrium selection, including Farrell (1988), Kim and Sobel (1995), Farrell and Rabin (1996), Blume (1998) and Demichelis and Weibull (2008).[2] Cooper, et al. (1992a) and Charness (2000) experimentally explore the role of mandatory cheap talk in the Stag-Hunt game. Consistent with their findings, one of our experimental conditions shows that universal cheap talk continues to promote efficient play in Stag-Hunt games even if message exchange is voluntary—when voluntary messages are costless, they are regularly used.

The design in the present paper differs from the experimental literature studying cheap talk in coordination games (Cooper, et al., 1992a; Charness, 2000; Blume and Ortmann, 2007) in two dimensions: sending a message is optional and requires bearing a small cost.[3] These features make our design similar to experimental tests of the effects of outside options and money burning on equilibrium selection. For instance, Cooper, et al. (1992b) study a Stag-Hunt game in which one player has access to an outside option. They find that conditional on a relevant outside option not being exercised, the predominant outcome is the Pareto-efficient equilibrium in the Stag Hunt, consistent with forward induction. However, unlike in Cooper, et al. (1992b), in our study the game is always played in the post-communication stage and we replace the one-sided outside option with a two-sided option to burn money prior to the game.

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[2] For theoretical analyses of the effectiveness of unilateral vs. multilateral communication, see Ellingsen and Östling (2010). In experiments, Cooper et al (1992) find that two-sided communication is more efficiency enhancing than one-sided communication. Weber et al. (2001) and Chaudhuri et al. (2009) find varying effectiveness of limited forms of communication. Other experimental evidence provides instances in which one-way communication yields high levels of efficiency (Charness, 2000; Duffy and Feltovich, 2002; Brandts and Cooper, 2007) or even out-performs two-way communication (Burton et al., 2005). Related research studies the effects on coordination of communication through different kinds of institutions (Kwasnica, Kogan and Weber, 2011; Shurchkov, 2016).

[3] A few recent studies explore costly pre-play communication in coordination games. Manzini, Sadrieh and Vriend (2009) consider pre-play communication unrelated to game strategies—i.e., “smiles” that players can send to one another prior to playing the game. The use of smiles, though infrequent, slightly increases the frequency with which players select more efficient actions, but this infrequent use is insufficient to yield better coordination. When smiles are costly, they are used very infrequently (in less than 1 percent of cases). Fehr (2011) finds that players rarely vote to impose a costly communication regime, prior to merging two three-person groups playing a coordination game, resulting in coordination failure. This suggests that people fail to properly anticipate the benefit of costly pre-play messages in large groups. A similar finding is observed by Kriss, Blume and Weber (2016), who study optional costly communication in Weak-Link games. Andersson and Holm (2013) study two-sided costly communication in a market-entry coordination game. While sending messages aids coordination, subjects attempt to free-ride by refraining from sending messages in the hope that other players will do so.

Our design is most closely related to Huck and Mueller's (2005) experimental study of the role of a money-burning option in the Battle-of-the-Sexes game. The principal differences are that their base game is the Battle of the Sexes whereas ours is the Stag Hunt and that in our case *all* players have the option to burn money before playing the base game. Moreover, as we describe in more detail below, the forward induction logic in their paper can be captured through iterative deletion of dominated strategies alone, whereas in our setting it requires a reference to Nash equilibrium.[4]

A key attraction of our experimental design is that it lets us differentiate among alternative formalizations of the forward induction intuition. Elon Kohlberg (1981) first proposed forward induction as a property that Nash equilibria have to satisfy in order to be self-enforcing. He illustrated the principle using a game in which one player has a choice between an outside option and entering a Battle-of-the-Sexes game. If the value of the outside option is (strictly) between that player's pure-strategy equilibrium payoffs, then by forgoing the outside option he effectively communicates that he will take the action consistent with his preferred equilibrium payoff in the Battle of the Sexes. If the other player understands this message, this will undermine the equilibrium in which the outside option is chosen. The general principle at work here is that for an equilibrium to be self-enforcing it has to be "consistent with … deductions based on the opponents' rational behavior in the past" (Kohlberg, 1991). In the Battle of the Sexes with an outside option, the forward induction outcome is the only outcome that remains after iterative deletion of dominated strategies.

While at least some aspects of forward induction can be captured by (iterative) deletion of dominated strategies, Kohlberg and Mertens (1986) noted that their concept of strategic stability has stronger forward induction implications: a stable solution is not only robust to the elimination of dominated strategies but also to the elimination of strategies that are not best replies in any equilibrium supporting the solution.[5] This latter property, of robustness against deletion of never weak best replies, plays a key role in our design and in understanding our results.

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[4] There is no intuitive or theoretical basis for forward induction having a role in the Battle of the Sexes with two-sided money burning. For small message costs the equilibrium structure is similar to that with a simultaneous exchange of costless messages as in Farrell (1987) and Rabin (1994).

[5] Kohlberg and Mertens' (1986) strategic stability concept is formulated for the strategic form of the game. Van Damme (1989) provides an alternative definition of forward induction based on extensive form representations.

The Stag-Hunt game with optional costly communication belongs to the class of "money burning" games that were studied in an influential paper by Ben-Porath and Dekel (1992). They showed that as long as only one of the players has the option to send a costly message, that player achieves his preferred equilibrium in the subgame without sending a message as the unique outcome that survives iterated admissibility (IA), the deletion of all weakly dominated strategies at every step. This no longer true if, as in our experiment, both players can burn money. Thus, unlike in one-sided money-burning games, in two-sided money burning games the aspect of forward induction that is captured by iterated admissibility has no predictive power.[6]

Forward induction, however, regains some of its predictive power in two-sided money-burning games once we require that solutions are not only robust to deletion of dominated strategies but also to deletion of never best weak best replies. This is in line with Kohlberg and Mertens' conceptualization of FI. In the next section, we adopt this approach, using Govindan and Wilson's (2009) recent definition of forward induction (GW-FI). GW-FI applied to the pure-strategy equilibrium outcomes of the Stag-Hunt game with a two-sided money burning option predicts that the money burning option is not exercised and that the efficient equilibrium is played in the subgame. The key to understanding the difference in conclusions from applying IA and GW-FI to our game is that GW-FI takes an equilibrium outcome as a starting point. This reference to an equilibrium outcome gives GW-FI extra leverage. Our experimental results suggest that this extra leverage adds explanatory power.

The prior experimental evidence on forward induction is mixed. Huck and Mueller (2005) find support for the Ben-Porath and Dekel prediction when games are represented in extensive form, but not for the corresponding representation in strategic form. Brandts and Holt (1995) find support for forward induction predictions only in simple games, where forward induction is equivalent to elimination of dominated strategies. Cooper, et al. (1994) find partial support for the forward-induction hypothesis in the Battle-of-the-Sexes game with an outside

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[6] In the online appendix we analyze the forward induction implications of Pearce's (1984) extensive-form rationalizability, shown by Battigalli and Siniscalchi (2002) to correspond to *rationality and common strong belief in rationality* on complete type spaces; iterative admissibility, where in each round all weakly dominated strategies of all players are deleted (Brandenburger, Friedenberg and Keisler (2008) demonstrate that m+1 rounds of iterative deletion of weakly dominated strategies corresponds to *rationality and m-th order assumption of rationality* with complete type structures); and fully permissible sets, which where proposed by Asheim & Dufwenberg (2003). We show that none of these solutions concepts has explanatory power in the Stag-Hunt game with optional costly communication and reasonably costly messages.

option. Players benefit from having an outside option, but the outside option is frequently chosen when forward induction says that it should not be. While Van Huyck et al. (1993) find support for forward induction in experiments on auctioning the right to play median-effort games, Cachon and Camerer's (1996) results suggest that some of this may be due instead to loss avoidance. Blume and Gneezy (2010) find evidence for "cognitive forward induction"—players who find it difficult to coordinate on a non-obvious focal point achieve better outcomes when they are conscripted into playing the game by someone with an attractive outside option. On the other hand, like Cooper, et al. (1994), they find excessive use of the outside option. To the best of our knowledge, we are the first to look at forward induction in two-sided money burning games.

We also explore several potential alternative explanations of our findings. Neither level-k reasoning (Ellingsen and Östling, 2010) nor Quantal Response Equilibrium (McKelvey, R., and Palfrey, T., 1995; Anderson, S., Goeree, J., and Holt, C., 2001) can account for our results.[7] We can also rule out that our subject population simply exhibits a tendency to select the efficient equilibrium, as there is no tendency toward efficient play when either messages are unavailable or are available but unreasonably costly. Importantly, the behavior we observe is not the result of learning. The modal behavior of efficient play without message use is established right from the beginning and robust throughout. We can also rule out that efficient play in the Stag-Hunt subgame results from the mere availability of messages (which might create a focal point analogous to an irrelevant outside option (Cooper, et al., 1991)). When messages are too costly to be relevant they are not used and in the Stag-Hunt subgame the inefficient equilibrium prevails. This suggests that experimental subjects are sensitive to potential uses of relevant—but not of irrelevant—messages, consistent with forward induction logic.

The remainder of the paper is organized as follows. Section II presents our theoretical analysis and hypotheses. In Section III we describe our experimental design and in Section IV we report our experimental data. Section V discusses our findings.

II. Theoretical Analysis and Hypotheses

We experimentally investigate optional costly communication prior to the Stag-Hunt game

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[7] The analysis is available from the authors upon request.

represented in Table 1, taken from Cooper et al. (1992a). This game has two pure-strategy equilibria: a Pareto-efficient one, in which players take action 1, and a risk-dominant one, in which they take action 2. In addition there is a mixed-strategy equilibrium in which each player chooses action 2 with probably 4/5. Our communication game modifies this game in two ways. First, we add an initial stage in which both players simultaneously decide whether to send no message or a message, either "1" or "2," to the other player. Players then observe any message sent before selecting an action in the Stag-Hunt game. Second, we introduce a cost, $c \geq 0$, of sending message "1" or "2." We refer to the special case when $c = 0$ as costless messages.

With reasonable message costs ($c \in (0,200)$), Govindan and Wilson's (2009) formalization of forward induction (GW-FI) can be used to generate a behavioral prediction.[8] The key is an equilibrium dominance argument: Players should assign probability zero to strategies of their opponents that result in a lower payoff than from the equilibrium in question. Among all pure-strategy equilibrium outcomes only one survives Govindan and Wilson's forward induction condition. Specifically, GW-FI rejects *(i)* the equilibrium outcome in which neither player sends a message and both take action 1, *(ii)* the equilibrium outcomes in which players send costly messages and take action 2 and *(iii)* the equilibrium outcomes in which exactly one player sends a message and then both players take action 2. GW-FI does not reject *(iv)* the equilibrium outcome in which players send no message and take action 2.

The GW-FI conclusions can be understood via the following "forward-induction reasoning" (for the formal details, see the online appendix): Let the game be played between Ann and Bob. Consider the equilibrium outcome *(i)* and suppose that Ann (unexpectedly) observes a costly message from Bob. If she maintains her belief in Bob's rationality, she must reason that Bob expects at least the payoff from the equilibrium outcome in *(i)*. This, however, is impossible with costly messages unless Bob plans to take action 2. Thus, following Bob's message, Ann must believe that Bob will take action 2. Given those beliefs, Bob strictly prefers to deviate from *(i)*. Similarly, consider the equilibrium outcome *(ii)* and suppose that Ann (unexpectedly) observes no message from Bob. If this move by Bob is rational, then Bob must expect to get a payoff from this move that is at least as high as his payoff under the equilibrium outcome *(ii)***.**

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[8] Alternatively, our forward-induction prediction can be obtained by applying Kohlberg and Mertens' (1986) "never weak best reply" criterion, which requires that solutions be stable against the elimination of strategies that are not a best reply against any equilibrium supporting the solution.

This, however, requires that Bob take action 2 in the continuation game. Given this belief on Ann's part, Bob strictly prefers to deviate from *(ii)*. The argument for the equilibrium outcomes *(iii)* is essentially the same as for *(ii)*. Finally, the equilibrium outcome *(iv)* survives the GW-FI test since every deviation that changes this equilibrium outcome strictly lowers the deviating player's payoff. Thus among the pure-strategy equilibrium outcomes, only the one where players forgo messages and play efficiently survives.

The GW-FI prediction, that with reasonably costly messages, ($c \in (0{,}200)$), players predominantly send no message and take action 2 is of special interest for two reasons. First, it contrasts with Cooper et al. (1992a) and others, who found coordination difficult to achieve without pre-play messages. Second, it contrasts with alternative solution concepts, including iterative admissibility and extensive-form rationalizability, which capture forward-induction reasoning in other settings, but have essentially no predictive power here (see online appendix).

We also study situations with "costless communication" (c=0) and with "unreasonable message costs" (c>200)—i.e., where the cost of sending a message is greater than the payoff difference between the two pure-strategy outcomes in Table 1. In these cases, GW-FI does *not* single out players taking action 2 without sending messages.

With costless messages, the strategy of sending a message and then taking action 1 is a best reply to the equilibrium component that contains the equilibrium in which no messages are sent and action 1 is taken. Hence, unlike with reasonably costly messages, receiving an unexpected message is consistent with the other player continuing to play action 1 in the Stag-Hunt game. The case of costless messages closely resembles that of mandatory cheap talk, for which Cooper et al. (1992a) found that the typical outcome is for the efficient equilibrium to be reached. This and the fact that forward induction does not rule out any equilibria with optional costless messages suggests that, with the option to send costless messages (c = 0), the modal behavior will be for players to send message "2" and to take action 2.

With unreasonable message costs, sending a message is strictly dominated and therefore cannot be used to make deductions based on assuming rationality. The case of unreasonable message costs effectively takes us back to players having no access to messages. In this case, Cooper et al. (1992a) found that the inefficient risk-dominant equilibrium prevails. This suggests that with unreasonably costly messages ($c > 200$), the modal behavior will be for players not to send messages and to take action 1. Similarly, we expect that, with no messages, players will predominantly take action 1.

The above theoretical considerations motivate the following hypotheses regarding the role of message costs in driving behavior.

Hypothesis 1: *With no messages, the modal behavior will be for players to take action 1.*

Hypothesis 2: *With the option to send costless messages* ($c = 0$), *the modal behavior will be for players to send message "2" and to take action 2.*

Hypothesis 3: *With the option to send reasonably costly messages* ($c \in (0,200)$), *the modal behavior will be for players not to send messages and to take action 2.*

Hypothesis 4: *With unreasonably costly messages* ($c > 200$)), *the modal behavior will be for players not to send messages and to take action 1.*

Further theoretical support for our key prediction in the case of $c \in (0,200)$ is provided by Hurkens (1996), whose results imply that with reasonable message costs efficiency without message use it is the *unique* outcome that is supported by equilibria belonging to a minimal *curb* (closed under rational behavior) set (Basu and Weibull, 1991). Curb sets are sets of strategies that are closed under inclusion of best replies and minimal curb sets do not strictly contain another such set. In the case of a unique minimal curb set, as in our game, a player who reasons through the game in terms of iterating best replies will eventually find himself caught in the unique minimal curb set, regardless of his starting point. Minimal curb sets frequently capture forward induction intuition (e.g., in the Battle of the Sexes with an outside option and in the Battle of the Sexes with a one-sided money burning option). Each curb set contains a persistent retract (Kalai and Samet, 1984) and each persistent retract contains a strategically stable set of equilibria, which then satisfies the forward induction property articulated in Proposition 6 of Kohlberg and Mertens (1986).[9]

The curb notion can be also be used to make predictions for the cheap-talk environment, where $c = 0$. Blume (1998) studies multi-sided pre-play communication assuming that agreement on an equilibrium action profile confers an infinitesimal payoff boost on that profile.

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[9] Our game has mixed strategy equilibrium outcomes in which all message options, sending no message, sending message 1 and sending message 2, have strictly positive probability. While these outcomes pass the Govindan-Wilson test, persistence and the minimal curb condition suggest that these outcomes are fragile.

In the present setting his results imply that every strategy profile in the unique minimal curb retract is an efficient equilibrium in which each player sends message 2.

III. Experimental Design

The experiment is modeled after Cooper et al. (1992a), in which subjects played the game in Table 1 either with or without communication.[10] The experiment was conducted at the University of Pittsburgh's Experimental Economics Laboratory (PEEL). Each session in our study consisted of ten different subjects, recruited by email from a subject pool consisting primarily of students and staff from Carnegie Mellon University and the University of Pittsburgh.

At the beginning of a session, players sat at separate computers and read instructions on the screen as they were read aloud by the experimenter.[11] Before playing the game, every participant completed a quiz to verify understanding of payoffs, communication rules, and the matching procedure. The experimenter answered questions privately.

Subjects then played the Stag-Hunt game in Table 1 for 40 periods. Payoffs in the game were indicated in "Experimental Currency Units" (ECU) which were converted into cash at the end of the experiment at the rate of 2500 ECU = \$1. Subjects were paid for all 40 periods of the game, in addition to a \$2 initial payment.

In each period, subjects were randomly matched with another player. They were never shown ID numbers, so it was impossible to know if one had met a counterpart previously or what action the counterpart had played in any previous encounters.

In conditions with communication, the period began with a choice of whether to send a message. Subjects could click one of three buttons, corresponding to a message of "1" or "2" or to "No message." The relevant cost was displayed next to each option. Subjects then observed their opponent's message choice and indicated an action choice of 1 or 2 in the Stag-Hunt game by clicking on one of two options and confirming the choice.

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[10] Other than the treatment differences, our design choices generally follow those of Cooper et al., with the exception that we simplified procedures where possible and modified the design to collect more data. For example, instead of using 11 subjects with one excluded each period, we used 10 subjects. Instead of 11 practice rounds of a dominant strategy game followed by 22 real rounds, we included no practice rounds and 40 real rounds. Instead of each subject being matched with every other subject exactly twice, we used random matching. And finally, instead of a payoff procedure that involved a lottery, we directly converted all experimental earnings into U.S. dollars.

[11] The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007). Instructions for one treatment (with $c = 10$) are provided in the online appendix.

At the end of a period, subjects observed a feedback screen that showed them their own action choice, the action choice of their opponent in that period and their own payoff. In conditions with communication, this feedback screen also reminded subjects of their own and their opponent's decisions regarding message use.

At the end of the experiment, subjects were shown their total earnings in ECU for the experiment and the corresponding cash payment. Average earnings were $15.23 for an experiment lasting under one hour.

Experimental Conditions

The five conditions are summarized in Table 2, which also presents the relevant cost parameter, *c*, for each condition. The table also includes the predictions from Section II.

We conducted a baseline without communication (*No Messages*) in which subjects played the game repeatedly with re-matching after every period. In this treatment, participants played the Stag-Hunt game in Table 1 for forty periods. Each period, participants were anonymously and randomly re-matched, played the one-shot game, and saw the results of that period. In every period after the first, players saw the history of their own prior plays of the game, but did not know the identity or history of their current opponent.

Our four conditions with messages depart from Cooper et al.'s design in two main ways. First, we allowed subjects to choose whether to send a message. Therefore, in a *Costless Messages* condition subjects chose at the beginning of each period whether to send a costless message to their opponent. Payoffs were not directly affected by this choice. Subjects selected to send either "no message", a messages of "1", or a message of "2", by clicking on one of the three options on a screen. After every subject made this choice, and corresponding opponents were informed of the message choice, subjects proceeded to play the game in Table 1. While the Costless Messages treatment differs slightly from Cooper et al.'s two-way communication treatment, in which messages were costless but also mandatory, we expect the two treatments to be quite similar in that there is little reason for subjects in our Costless Messages condition not to send messages. This prediction is also consistent with our Hypothesis 2.

Our second modification is more important. We include three conditions in which messages are costly, meaning that a player's payoff from Table 1 was decreased by a cost, *c*, if that player chose to send a message to her opponent. There was no cost if a player chose not to send a message, and subjects always observed, at no cost, any message from the opponent. Subjects made their choices in exactly the same manner as in the Costless Messages condition, except that now the cost of sending a message, in ECU, was presented next to the possible message choices "1" and "2", while the "no message" option explicitly indicated no cost.

Our three costly communication conditions varied the cost associated with sending a message. In two conditions with *Reasonably Costly* messages ($c \in (0,200)$), RC-10 and RC-100, sending a message cost 10 and 100 ECU, respectively. In a condition with *Unreasonably Costly* messages ($c > 200$), UC-300, sending a message cost 300 ECU. Our earlier analysis predicts different behavior for the two kinds of message costs, as presented in Table 2.

IV. Results

We conducted three sessions each of the Costless Messages and No Messages conditions, seven sessions each of the two conditions with Reasonably Costly messages, RC-10 and RC-100, and five sessions of the condition with Unreasonably Costly messages (UC-300), using a total of 250 subjects. In our analysis, we explore several different characteristics of the results, including the sending of messages, aggregate action choices and outcomes, individual behavior, and earnings.

A. Message Use

The first question we ask is how message costs affected the frequency of message use. Recall that our analysis predicted that message "2" would be very frequent with Costless Messages but less frequent in the three conditions with Costly Messages (see Table 2).

We find that message costs strongly affect message use. Under Costless Messages, message "2" was sent 89.3 percent of the time. However, with positive message costs, far fewer messages were sent: the frequency of message "2" was 24.4 percent for $c = 10$, 11.3 percent for $c = 100$, and 4.8 percent for $c = 300$.[12] Thus, the aggregate data generally support our predictions concerning message use – message "2" is used very frequently with Costless Messages, but rarely in all conditions with Costly Messages.

Table 3 reports linear probability models, with subject random effects, using the choice to

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[12] As expected, message "1" was sent very rarely (never more than 1.2 percent of the time in any condition). In a large majority of these cases (86 percent), subjects followed a message of "1" by playing action 1, and no subject sent message "1" and subsequently chose action 2 more than one time in the forty periods.

send message "2" as the dependent variable.[13] The regressions use only data from the four treatments in which messages were possible and leave the Costless Messages condition as the omitted category. As model 1 reveals, the frequency of message use is significantly lower in all Costly Message conditions, relative to the condition with Costless Messages.[14] Thus, message costs—even very small ones as in RC-10—significantly decrease message use.[15]

To explore possible heterogeneity in message use across subjects, Figure 1 shows the distributions of message frequency by subject in each of the four conditions with communication. Each graph shows, for a particular condition, how often a subject sent message "2", represented on the horizontal axis, ranging from never (0) to doing so in every period (1). The vertical axis presents the frequency of each particular message use profile among subjects in that condition. When messages were Costless, a large majority of subjects sent message "2" in every period.[16] However, in the three Costly message conditions, the modal behavior was to send no messages at any point in the experiment.

While we find, as predicted, that subjects used messages far less frequently in the Costly Message conditions, there exists a possibility that this difference surfaced over the course of the experiment, and that subjects in all conditions initially sent messages with high frequency, but stopped doing so in the Costly Message conditions. The data reject this interpretation. We find very little difference in message use early and late in the experiment. In the online appendix (see Table C.1), we compare the frequencies of message use in Periods 1 vs. 40 and in Periods 1-10 vs. 31-40. Across all comparisons, the frequencies of message use never differ by more than 7

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[13] Throughout our analysis, we report linear models to facilitate interpretation of the coefficients. Appendix C (available online) presents probit models that better account for the binary dependent variable and produce similar results. We also estimated the models in Table 3 that include more than one period of data with period fixed effects; the results are substantively unchanged.

[14] In a more conservative statistical test, we calculate the frequency of message "2" use in a session and use this session-level statistic as the unit of observation in a non-parametric Wilcoxon rank-sum test of differences across conditions. The difference in frequency of message "2" use between the Costless Message condition and either RC-10, RC-100, or UC-300 is statistically significant (respectively, $z = 2.39$, $p < 0.02$; $z = 2.39$, $p < 0.02$; and $z = 2.24$, $p < 0.03$). Among the conditions with Costly Messages, only the difference between RC-10 and UC-300 is statistically significant ($z = 2.36$, $p < 0.02$).

[15] The coefficients for the three Costly Message conditions in model 1 differ significantly and are ordered such that fewer messages are used as costs increase. While our predictions do not account for any differences between the three treatments with costly messages, it is not entirely surprising to find fewer messages with higher costs.

[16] Three subjects in Costless Messages rarely or never sent message "2" even though doing so was costless. One of these subjects informed us, at the end of the experiment, that he had poor vision and experienced difficulty reading the screen and clicking on the radio buttons. The other two repeatedly played action 1, and sent the corresponding message, perhaps out of altruism (i.e., to ensure that their opponent did not receive the zero payoff).

percent and are never statistically significant. Moreover, as model 2 in Table 3 reveals, there is no significant trend in message "2" use across periods in any condition, while model 3 reveals that message use was significantly lower under costly messages when considering only the first period. Additionally, the frequency of message "2" is never much higher in any period of the Costly message conditions than the corresponding aggregate frequencies above—the highest frequencies of message "2" use in any period are 34.2 percent in RC-10, 17.1 percent in RC-100, and 12 percent in UC-300—and this frequency is never lower than 83.3 percent in any period of the Costless Messages condition. Hence, we find little evidence that message use changes substantially across time.

Model 4 in Table 3 reveals an interesting aspect of how subjects respond to opponents' behavior. The model adds an explanatory variable indicating whether a subject's opponent in the prior period sent a message of "2." The coefficient for this variable is positive and statistically significant. Hence, observing message use by an opponent seems to lead subjects to believe that messages are necessary. However, the magnitude of the coefficient is relatively small, consistent with the above observation that dynamics play a minor role in message use.

The message use by subjects in the experiment therefore strongly confirms the first part of our predictions in Table 2. Whether on aggregate, by individual subject, or across periods, costless messages are used with very high frequency, while costly messages are used rarely.

B. Actions in the Stag-Hunt Game

We now consider the second part of the predictions in Table 2, that the modal behavior in the post-message subgame should be action 2 when messages are Costless or Reasonably Costly (RC-10 and RC-100) and action 1 when messages are either Unreasonably Costly (UC-300) or there are No Messages. Figure 2 presents the frequency of action 2 choices across periods, separately for each treatment.

Under No Messages and Costless Messages, we expected to replicate the findings in Cooper et al. (1992), who found efficient coordination rare when pre-play communication was not possible but frequent under costless communication. Consistent with Hypothesis 1, this is also generally the case in our data. Action 2 was chosen only 42 percent of the time with No Messages, and only 30 percent of the time in the final ten periods. With Costless Messages, Hypothesis 2 predicted that a high frequency of message "2" would support a high frequency of action 2 choices. Having already observed a high frequency of "2" messages, the 87 percent of choices of action 2 further corroborates our prediction.

We next consider Reasonably Costly messages ($c \in (0,200)$). Despite the low frequency of message use in these conditions, we observe high frequencies of action 2 in both RC-10 (83 percent) and RC-100 (76 percent), and these are similar to the frequency observed with Costless Messages (87 percent). In fact, by the final 10 periods action 2 was selected between 80 and 83 percent of the time in *all three* of the conditions where we predicted a high frequency of that action, despite the very different frequencies of message use. Thus, combining the frequency of messages and action 2 choices in the treatments with Reasonably Costly messages, we find strong support for our main prediction (Hypothesis 3). The availability of optional, and reasonably costly, pre-play messages seems sufficient to obtain a high frequency of efficient coordination—subjects do not actually have to use the messages.

Finally, we consider the condition with Unreasonably Costly messages, UC-300, where we predicted the modal choice in the Stag-Hunt game would be action 1 (Hypothesis 4). The data also confirm this prediction: action 2 is selected 28 percent of the time in this treatment, and this frequency converges downward over the course of the experiment.[17] Thus, while message use was infrequent in all conditions with Costly messages, forgone messages only facilitated efficient coordination in the two conditions with Reasonably Costly messages, as we predicted.

Table 4 reports random-effects linear probability models that use as the dependent variable whether a subject chose action 2 in a period. The first model confirms our predictions regarding behavior across treatments: action 2 is chosen significantly more frequently with Costless or Reasonably Costly Messages, than with either No Messages (the omitted category) or Unreasonably Costly Messages. We fail to reject the restriction that the three coefficients for Costless Messages, RC-10, and RC-100 are equal ($\chi^2(2) = 3.87$, $p = 0.14$).

Model 2 includes time trends for each condition, and confirms some patterns from Figure 2. For example, the frequency of action 2 decreases across periods both with No Messages and

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[17] Note that there is a slight gap that opens up between UC-300 and No Messages in the second half of the experiment (as we show below in Table 4, the time trend differs significantly for these conditions). This is due to heterogeneity across sessions in the No Messages condition (see Figure 5 and Appendix Figure C.1 online). In two sessions, convergence to action 1 occurred as predicted, while in the remaining No Message session behavior converged to action 2. Therefore, coordination on the inefficient game equilibrium (1,1) is weaker than that observed by Cooper et al. (1992), though we find it to be the case in two of three sessions. Some procedural differences between the two experiments may explain the disparity (see footnote 11).

Unreasonably Costly Messages, and the decrease is larger with the latter. More importantly, in model 2 the intercepts and time trends differ for the three remaining conditions (Costless, RC-10 and RC-100). While the difference between the coefficients for these three intercepts is statistically significant ($\chi^2(2) < 15.50$, $p < 0.001$), the differences in the frequencies of first-period action 2 choice across these three conditions are small (Costless: 90 percent; RC-10: 79 percent; RC-100: 80 percent) and none of the pairwise first-period comparisons at the subject level are statistically significant ($\chi^2(1) < 1.83$, $p > 0.17$, in all comparisons). To further explore differences in first period behavior, model 4 in Table 4 reports the same regression as model 1, but using only first period data. The coefficients for the three conditions in which we predicted a high frequency of action 2 choices—Costless Messages and the two conditions with Reasonably Costly messages—are positive and significant, jointly significantly different from zero ($F_{2,245} = 4.07$, $p < 0.01$), and do not differ statistically from each other ($F_{3,245} = 0.78$, $p = 0.46$).[18]

To summarize, our analysis so far strongly confirms all of our hypotheses. Confirming prior research, subjects who cannot send messages tend to select action 1 (Hypothesis 1), while costless messages facilitate action 2 (Hypothesis 2). However, messages appear unnecessary when they are Reasonably Costly ($c \in (0,200)$), as subjects in these conditions do not send messages, yet they select action 2 with frequencies very similar to those under Costless messages. This supports our main prediction (Hypothesis 3).

Moreover, the interpretation that the higher action 2 frequencies with forgone costly messages are due to the kind of reasoning underlying forward induction is further supported by the fact that, as message costs become unreasonable ($c > 200$), subjects send few messages but modal behavior changes dramatically toward action 1 (Hypothesis 4). Thus, the inference subjects' draw from the reasonableness of a forgone message seems critical. All of this is supported both when considering either data from all 40 periods or only the first period.

C. Individual Actions Conditional on Messages

Our prior analysis confirms our hypotheses when looking, separately, at message and

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[18] As with Table 3, we re-estimated the relevant models with period fixed effects and find no substantive change. Also as with Table 3, we studied whether experience with opponents' prior message use affects action choices. Specifically, we estimated a version of model 1 in Table 4 that includes an additional explanatory variable identifying whether a subject's opponent in the prior period sent a message. The coefficient for this variable is statistically insignificant and its inclusion has no substantive effect on the other variable coefficients.

choice behavior. To provide a stronger test, we also consider these two aspects of a player's strategy jointly. At the root of our main prediction (Hypothesis 3) is that subjects in the conditions with Reasonably Costly messages select action 2 with high frequency when they do not receive a message from their opponent, but that subjects in the Unreasonably Costly and No Message conditions select action 1 in the absence of messages.

Figure 3 shows the frequencies of action choices 2 (dark shading) and 1 (light shading) conditional on a message of "2" being sent or received in each condition. The label above each panel presents the message profile, (message sent, message received), indicating both the message sent by the subject and the message received from the opponent. The percentages over each bar indicate the frequency in that particular condition for that particular message profile. For example, the bottom right panel, labeled (2,2), presents instances in which both the focal player and her opponent sent message "2", which occurred with a frequency of 80 percent under Costless Messages, 8 percent in RC-10, 2 percent in RC-100, and never occurred in UC-300 or, of course, under No Messages. In this panel, it is apparent that when a player both sent a message and also received a message from the opponent, the player chose 2, regardless of message cost (at least for $c < 200$).

Turning to the diagonal panels, in which a subject either sent no message but received one (none, 2) or sent a message but did not receive one (2, none), we find interesting differences between the communication treatments. In particular, with Costless Messages, such communication outcomes resulted in fewer than half of subjects playing action 2 subsequently.[19] However, in the conditions with Reasonably Costly messages (RC-10 and RC-100) the proportion of action 2 choices is much higher in both panels, and is close to one.

Most importantly for our purposes, consider the top-left panel, when no messages are sent. Under the complete absence of messages, subjects are more likely to choose action 2 when sending a message would have been Reasonably Costly (RC-10: 75.5%; RC-100: 71.8%) than when sending a message was Unreasonably Costly (22.5%) or simply not possible (42.4%).[20] Thus, as we hypothesized, the absence of messages results in different action responses based on

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[19] Note that the Costless Messages data in the (none, 2) panel is almost entirely composed of the three subjects with irregular message behavior (see footnote 16). The Costless Messages data in the (2, none) panel is composed almost entirely of *responses* to these subjects by their opponents.

[20] The frequency of action choice 2 under Costless Messages in the top-left (none, none) panel is not highly informative as this message profile occurred very infrequently.

whether sending a message would have been reasonable or possible.

To provide statistical evidence that the absence of messages is interpreted differently under Reasonably Costly messages than in other conditions, model 3 in Table 4 explores how behavior changes across conditions in response to receiving a message of "2" from an opponent. Since a subject's own message is endogenous, we do not include own message as an explanatory variable. When including whether a message was received, the coefficient for the Costless Message condition becomes small and statistically insignificant, while the coefficient for Received Message "2," which applies to this condition, is large and statistically significant. This shows that simply being in the Costless Message condition does not increase the likelihood of an action 2 choice—when messages are costless it is also necessary that one's opponent send a message of "2." However, the coefficients for the two conditions with Reasonably Costly messages are positive and statistically significant, indicating that receiving messages is unnecessary in these conditions to see an increase in action 2 choice frequencies. That is, action 2 choices increase significantly from simply being in these conditions, regardless of whether a message of "2" is received. This is consistent with our primary hypothesis (H3), that the possibility of reasonably costly messages is sufficient to facilitate play of action 2, even when messages are not actually used.[21]

The above analysis pools behavior across all periods and therefore may reflect cohort effects and path dependencies. Therefore, to conduct a conservative statistical test of this finding, in models 4 and 5 we examine behavior in the first period alone. Model 4 shows that the greater tendency to play action 2 in the conditions with Costless and Reasonably Costly messages is present from the first period. Model 5 studies the frequency of period 1 action 2 choices *only* in cases where no messages were used by either player.[22] The model confirms the above analysis—the absence of any messages yields at least marginally significantly more action 2 choices in both conditions with Reasonably Costly messages, relative to when messages are not possible, but no significant increase when messages are Unreasonably Costly. Thus, even from the first period, subjects who play the Stag-Hunt game without either receiving a message from or

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[21] The negative coefficients on the interaction between the costly message conditions and Message "2" indicate that the effect of receiving a message is weaker under costly messages than under costless messages.

[22] This occurred 40 percent of the time in RC-10, 63 percent in RC-100, 92 percent in UC-300, and (by construction) 100 percent of the time under No Messages. The no-messages case did not occur under Costless Messages, where every pair in Period 1 had at least one message, so we omit this condition from the model.

sending one to an opponent behave differently depending on what type of communication was possible, in a manner consistent with our predictions.

Figure 4 explores whether responsiveness to messages in the two Reasonably Costly message conditions varies across periods. The graphs show the frequency of action 2 choices across periods, following either receiving (thin solid line) or not receiving (thick solid line) a message. The graphs also show the frequency of message "2." In both conditions, subjects are slightly more likely to select action 2 when they receive a message of "2" from their opponent than when they do not, but the frequencies in both panels are quite high regardless of whether or not a message was received. The graphs also reveal little change in behavior over time.[23]

Finally, note that the prediction in Hypothesis 3 for the games with reasonably costly messages can be supported as equilibrium behavior only if it is, in fact, more profitable to play action 2 following the absence of messages than to play action 1. Table 5 presents, for each possible message profile in which at least one subject in a pair did not send a message, the corresponding average realized profits for the two possible action choices in the Stag-Hunt game. Note that the payoff for action 1 is always 800, since this guarantees that payoff regardless of the opponent's choice. Notice that choosing 2 is more profitable than choosing 1 following the absence of a message in both conditions with Reasonably Costly messages (RC-10 and RC-100). That is, a subject who either did not send a message or did not observe one from an opponent does better, on average, by nevertheless choosing 2 in the game. However, the opposite is true in the remaining three conditions (Costless Messages, RC-300 or No Messages).

D. Variation Across Time - Learning

One might worry that our appeal to forward induction as the principal explanation for the central tendency in our data relies on an undue faith in the subjects' introspective abilities. This would be especially true if we observed that the modal behavior of efficient play without messages only arose after repeated play. Subjects might, for example, initially use messages to

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[23] We find some evidence that subjects in RC10 and RC100 learn to play action 2 in response to not observing a message from an opponent. Specifically, if we consider cases in which *(i)* a subject played action 1 in period t-1, *(ii)* the subject's opponent in period t-1 sent no message, and *(iii)* neither the subject nor the current opponent sent messages in period t, then subjects whose period t-1 opponent played action 2 are more likely to play action 2 (25% of the time) than those whose period t-1 opponent played action 1 (5%). This difference in proportions, which is highly significant ($z = 7.99$, $p < 0.001$), suggests that at least some subjects learn through experience to have confidence that an opponent will play 2 even in the absence of messages.

coordinate on action 2 and then learn to sustain this outcome while dispensing with the use of messages. While this concern is plausible, the evidence suggests that it is unfounded.

First, as we note earlier, in the treatments where messages are available and at most reasonably costly, we see no significant trends in the use of message 2. This is evident in Figure 4 and in the fact that the coefficient on period (and on period interacted with treatment) in model 2 of Table 3 is small and statistically insignificant.

Second, in the treatments where messages are available and at most reasonably costly, Figure 2 indicates that the frequency of action 2 is essentially constant over time. Notice also that in model 2 of Table 4 the coefficient on Period representing the baseline No Message treatment is -0.007 and that the coefficient on Period X RC-10 representing the effect in RC-10 relative to the No Message baseline is 0.007. The net effect of combining these two time trends is not significantly different from zero. Similarly, the sum of coefficients on Period and on Period X RC-100 is also very close to zero. This is in sharp contrast to the treatments where messages are either unavailable (no messages) or prohibitively costly (UC-300), where we see significant declines in the frequency of action 2. Thus, while there is clear evidence for learning in the direction of action 1 without messages or with unreasonably costly messages, learning appears to play little or no role in determining action choices when messages are reasonably costly.

Third, as indicated in Figure 4, there is essentially no change over time in the frequency of action 2 conditional on receiving no message and hardly any change in the frequency of action 2 in response to receiving message 2.

Fourth, the positive impact on the frequency of action 2 choices of making reasonably costly messages available, despite the fact that these messages are typically not used, is already observed in period 1, as indicated in models 4 and 5 of Table 4. Note that when we pool the data from treatments RC-10 and RC-100 (which are not theoretically distinguished by the GW-FI analysis) the coefficient on the treatment effect in model 5, which uses only first period data and in which no messages were sent, is positive (0.231) and significant at the 5% level (p=0.025). Thus, the greater tendency to play action 2 following no messages in the conditions with Reasonably Costly messages is present from the first period.

As one might expect, the forward induction prediction does not account for all behavior either in the first period or in subsequent periods. In a small but persistent fraction of observations subjects send messages in the RC-10 and RC-100 treatments. There is also some churning, with some subjects moving from forgoing messages in one period to sending messages in the next period and vice versa. For example, of the 32 (42) RC-10 (RC-100) subjects who achieved the efficient equilibrium without communication in the first period, 26 (37) again sent no message in period 2 and 6 (5) sent message 2. Figure 1 shows that in the treatments with reasonably costly messages churning is confined to a subset of subjects; the modal behavior is to never send a message. Thus, while there may be individual instances of subjects learning to forgo messages, the modal pattern of behavior is established from the first period on and does not emerge over time as a result of learning.

E. Heterogeneity Across Sessions

Most of our prior analysis aggregates behavior across sessions, which may hide between-session heterogeneity. We present, in Figure 5, results from the individual sessions for each condition. The horizontal axis indicates the frequency of message "2" in a session, while the vertical axis indicates the frequency of action 2. The gridlines divide the graph into quadrants, three of which correspond to predicted message and action frequencies from our hypotheses (see Table 2):[24] low message frequency and high action 2 frequency under Reasonably Costly messages (H3), high message frequency and high action 2 frequency under Costless Messages (H2), low message frequency and low action 2 frequency under Unreasonably Costly (H4) or No Messages (H1). With few exceptions the sessions within a particular condition lie in the appropriate quadrant—the exceptions are: one RC-10 session had slightly more than 0.5 message frequency (0.51), one RC-100 session had a low action 2 frequency (0.35), and one session with No Messages obtained a high frequency of action 2 (0.85, see footnote 17). But the remaining 22 sessions all lie in the appropriate quadrant, providing strong support for our predictions. All but two (of 14) sessions with Reasonably Costly messages had both message frequencies below 0.44 and action 2 frequencies above 0.56, and five sessions in these conditions had both message frequencies below 0.04 and action 2 frequencies above 0.90 (these are the sessions clustered towards the top left of the graph). Note, however, that while the RC-10 and RC-100 data points tend to lie in the appropriate quadrant of the graph, there are slight differences in tendencies between the conditions, with RC-10 trending generally more rightward (more frequent messages)

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[24] To account for possible noise in the data, our hypotheses stated predictions in terms of modal behavior. More precise predictions correspond to the corner in each quadrant where message and action frequencies are either 0 or 1.

and upward (higher frequency of action 2). Meanwhile, no session with Unreasonably Costly messages obtained an action 2 frequency greater than 0.3. Thus, the behavior in a large majority of sessions generally conforms to our predictions.

V. Discussion and Conclusion

Much of what we know about the coordinating powers of communication in the laboratory concerns mandatory communication, in which case communication is, de facto, free. In practice, communication is rarely ever either mandatory or completely free, leaving one wondering about the robustness and external validity of the cheap-talk results from the experimental literature.

Our experimental results suggest that there is reason for concern. Even small message costs dramatically reduce message use. We suspect that this observation generalizes to other pre-play communication environments.

In the specific setting that we study, where communication precedes a Stag-Hunt game, we find that the reduction in communication due to moderate communication costs does not significantly impair efficiency. The finding is surprising because we know from prior work that in Stag-Hunt games without communication there is a strong tendency for inefficient risk-dominant play to prevail. We suspect that since the forward-induction argument that drives our predictions does not apply to generalizations of the Stag Hunt with more than two players, this result will not extend beyond dyads. Nevertheless, given that a great deal of communication does occur in dyads, it is heartening to see that at least there the option to communicate may be enough to achieve efficiency without communication. Hence, when pairs or small groups attempt to coordinate outside the laboratory, it may often be sufficient for them to be aware of the possibility of costly communication for them to do so efficiently. They may not actually need to incur the costs of repeated communication to coordinate every action. For example, in workplace and social settings, people may often hold recurring weekly meetings without having to reach explicit agreement every week that the meeting will take place—but knowing that if any party involved felt it was necessary to coordinate a particular aspect of the meeting, such as a change in venue or confirmation that the meeting will take place the day before a holiday, they have the opportunity to use costly communication for this purpose.

At the same time, the dramatic drop in communication in response to moderate increases in communication costs that we observe may have more damaging consequences in large groups.

Continuing with the example above, if there are 30 people that need to attend the meeting—and the meeting is useless if any of them does not attend—then the absence of communication may produce sufficient doubt that everyone will be there to yield very different results than what we find here with two-player Stag-Hunt games. Indeed, in a separate paper (Blume, Kriss and Weber, 2015), we study voluntary costly communication in nine-player minimum-effort coordination games and find that infrequent use of costly messages can have a more serious effect on coordination and efficiency.

Finally, our results shed light on the theory and practice of forward induction. Our experiment falls within the class of money-burning games. For those games forward induction has a striking implication: If only one player has the option to burn, that player receives his preferred equilibrium payoff in the base game without having to exercise his option. Formally, this can be articulated in terms of iterative dominance. In contrast, in the setting we examine, where both players have the option to burn, iterative dominance and appeals to common knowledge of rationality alone are not enough to select the outcome where players achieve efficiency in the base game without burning money. To account for our data, the forward induction intuition appears to be better captured through a version of equilibrium dominance.

A sensible alternative (to forward induction) intuition of how subjects might view not receiving a message is this: If messages are an expression of commitment to efficient play, then not receiving a message is an indicator of lack of such commitment. Therefore failure to receive a message would be an indicator of the opponent using the risk dominant action, which in turn would call for a risk dominant reply. This reasoning, while sensible, is not supported by the data. Why? There is plenty of evidence from the experimental cheap-talk literature (Cooper, DeJong, Forsythe and Ross, 1992a; Blume and Ortmann, 2007) that message use by both sides is an effective way to bring about efficient play. Moreover, in those experiments subjects understand this role of messages right from the beginning; it is not learned, and does not appear to require a high degree of rationality. Making messages costly, and thus allowing subjects to "put their money where their mouth is," makes them more credible. Therefore, subjects have a way of achieving efficiency, and the experimental cheap-talk literature suggests that they take advantage of this fact. All that forward induction requires to account for our data is that subjects interpret not receiving a message in this context: *Since they understand that exchanging messages achieves efficiency and that others understand this as well, failure to receive a message cannot* *be a signal of lack of trust in messages, and must instead be interpreted as a deliberate calculation that messages are not necessary to achieve efficient coordination.*

We are not aware of any candidates for alternative explanations of our data. In particular, none of the standard bounded-rationality approaches to games, such as learning, Level-k reasoning and Quantal Response Equilibrium predict efficiency without message use in the reasonable cost case. Hence, despite the seemingly strong rationality requirements underlying a theoretical interpretation based on forward induction, we believe it to be the most adequate interpretation for our data.

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Table 1: Stag-Hunt Game

		Column Player's Action	
		1	2
Row Player's Action	1	800, 800	800, 0
	2	0, 800	1000, 1000

Table 2: Experimental Conditions

Communication Condition	**Message Cost (in ECU)**	**Prediction (message, action)**
No Messages	-	- , action 1 (H1)
Costless Messages	c = 0	message "2", action 2 (H2)
Reasonably Costly Messages (RC-10)	c = 10	no message, action 2 (H3)
Reasonably Costly Messages (RC-100)	c = 100	
Unreasonably Costly Messages (UC-300)	c = 300	no message, action 1 (H4)

Table 3: Random-effects Linear Regressions of Message “2” Use

Dependent variable: Subject sent message “2”	All periods		Period 1	Periods 2 - 40
	(1)	(2)	(3)	(4)
Reasonably Costly Messages (RC-10)	-0.649***	-0.670***	-0.490***	-0.638***
	(0.053)	(0.055)	(0.081)	(0.052)
Reasonably Costly Messages (RC-100)	-0.780***	-0.804***	-0.690***	-0.765***
	(0.053)	(0.055)	(0.081)	(0.052)
Unreasonably Costly Messages (UC-300)	-0.845***	-0.845***	-0.813***	-0.827***
	(0.056)	(0.058)	(0.085)	(0.055)
Period		0.000		
		(0.001)		
Period X Reasonably Costly Messages (RC-10)		0.001		
		(0.001)		
Period X Reasonably Costly Messages (RC-100)		0.001		
		(0.001)		
Period X Unreasonably Costly Messages (UC-300)		0.000		
		(0.001)		
Opponent in previous period sent message “2”				0.023***
				(0.008)
Constant	0.893***	0.890***	0.833***	0.875***
	(0.044)	(0.046)	(0.067)	(0.044)
Observations	8,800	8,800	220	8,580
Number of subjects	220	220	220	220
R^2	0.386	0.387	0.324	0.391

All models include data from all conditions with messages; models 1, 2 and 4 include subject random effects
Standard errors in parentheses; * - $p < 0.1$; ** - $p < 0.05$; *** - $p < 0.01$

Table 4: Linear Random-effects Regressions of Action Choice 2 in Stag-Hunt Subgame

Dependent variable: Subject chose action 2	All periods			Period 1	Period 1 & no messages
	(1)	(2)	(3)	(4)	(5)
Costless Messages	0.446^{***} (0.071)	0.365^{***} (0.075)	0.056 (0.073)	0.367^{***} (0.111)	
Reasonably Costly Messages (RC-10)	0.407^{***} (0.060)	0.265^{***} (0.063)	0.359^{***} (0.058)	0.252^{***} (0.094)	0.217^{*} (0.123)
Reasonably Costly Messages (RC-100)	0.339^{***} (0.060)	0.159^{**} (0.063)	0.293^{***} (0.057)	0.267^{***} (0.094)	0.239^{**} (0.111)
Unreasonably Costly Messages (UC-300)	-0.145^{**} (0.064)	0.017 (0.067)	-0.167^{***} (0.061)	0.027 (0.099)	0.054 (0.110)
Period		-0.007^{***} (0.001)			
Period X Costless Messages		0.004^{***} (0.001)			
Period X RC-10		0.007^{***} (0.001)			
Period X RC-100		0.009^{***} (0.001)			
Period X UC-300		-0.008^{***} (0.001)			
Received Message “2” (Costless Messages)			0.437^{***} (0.030)		
Received Message “2” X RC-10			-0.242^{***} (0.033)		
Received Message “2” X RC-100			-0.030 (0.036)		
Received Message “2” X UC-300			0.029 (0.044)		
Constant	0.424^{***} (0.050)	0.564^{***} (0.053)	0.424^{***} (0.048)	0.533^{***} (0.079)	0.533^{***} (0.086)
Observations	10,000	10,000	10,000	250	148
Number of subjects	250	250	250	250	148
R^2	0.231	0.261	0.253	0.081	0.046

Models 1 through 4 include data from all conditions; model 5 omits Costless Messages condition; models 1 through 3 include subject random effects.
Standard errors in parentheses; * - $p < 0.1$; ** - $p < 0.05$; *** - $p < 0.01$

Table 5: Average Payoff by Action Choices Following Message Profiles

	Opponent sent no message		**Player sent no message**		**Neither player nor opponent sent message**	
	Action 1	*Action 2*	*Action 1*	*Action 2*	*Action 1*	*Action 2*
Costless Messages	800	392.9	800	666.7	800	333.3
		(65.9)		(83.3)		(210.8)
	N=58	N=56	N=81	N=33	N=6	N=6
Reasonably Costly Messages (RC-10)	800	837.9	800	842.5	800	809.0
		(9.0)		(8.9)		(11.2)
	N=434	N=1672	N=443	N=1663	N=403	N=1241
Reasonably Costly Messages (RC-100)	800	894.8	800	900.7	800	891.3
		(7.2)		(7.0)		(7.8)
	N=635	N=1834	N=647	N=1822	N=620	N=1582
Unreasonably Costly Messages (UC-300)	800	444.7	800	461.7	800	391.0
		(22.5)		(23.0)		(24.5)
	N=1398	N=488	N=1416	N=470	N=1373	N=399
No Messages					800	719.1
						(19.9)
					N=691	N=509

The first number in each cells presents the mean payoff (in ECU) for that action choice following the corresponding message profile. The numbers in parentheses are standard errors.

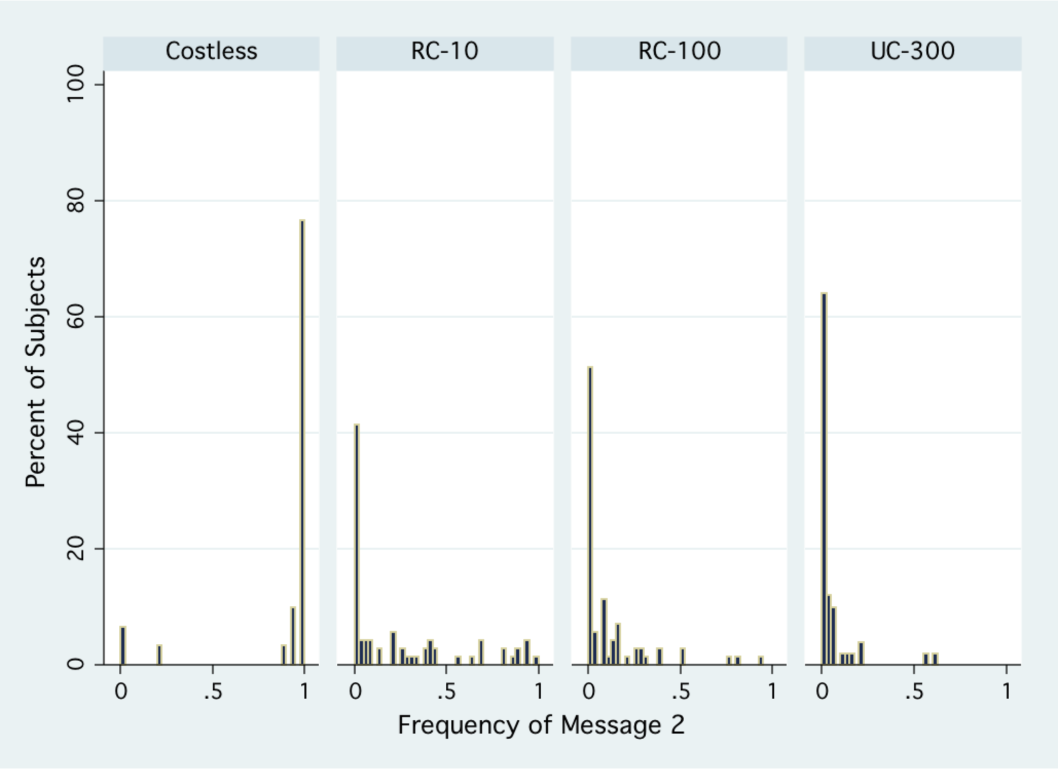

Figure 1: Distribution of Individual Frequency of Message Use by Condition

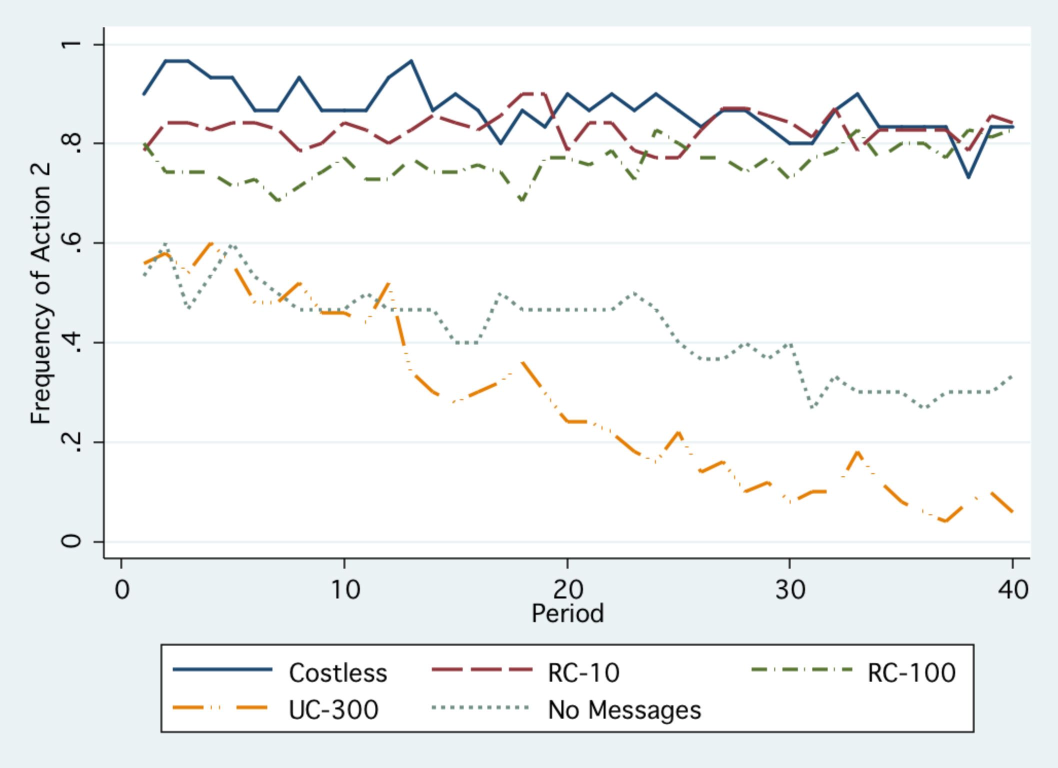

Figure 2: Action Choice over Time

Note: each panel in the figure corresponds to a particular message profile (own message, opponent's message) from the perspective of the relevant subject. Each bar within a panel shows the frequencies of subject's action choices of 1 (light) or 2 (dark) given that particular realized message profile. The percentages at the top of each bar indicate how frequently that message profile occurred in the corresponding condition.

Figure 3: Choices Conditional on (Message Sent, Message Received)

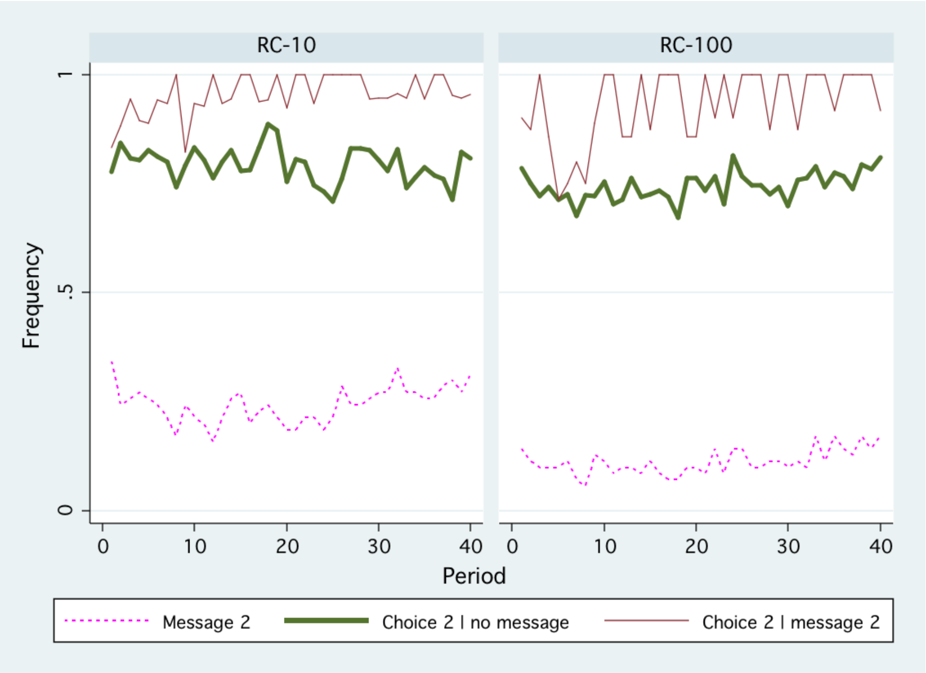

Figure 4: Choices Conditional on Message Received over Time

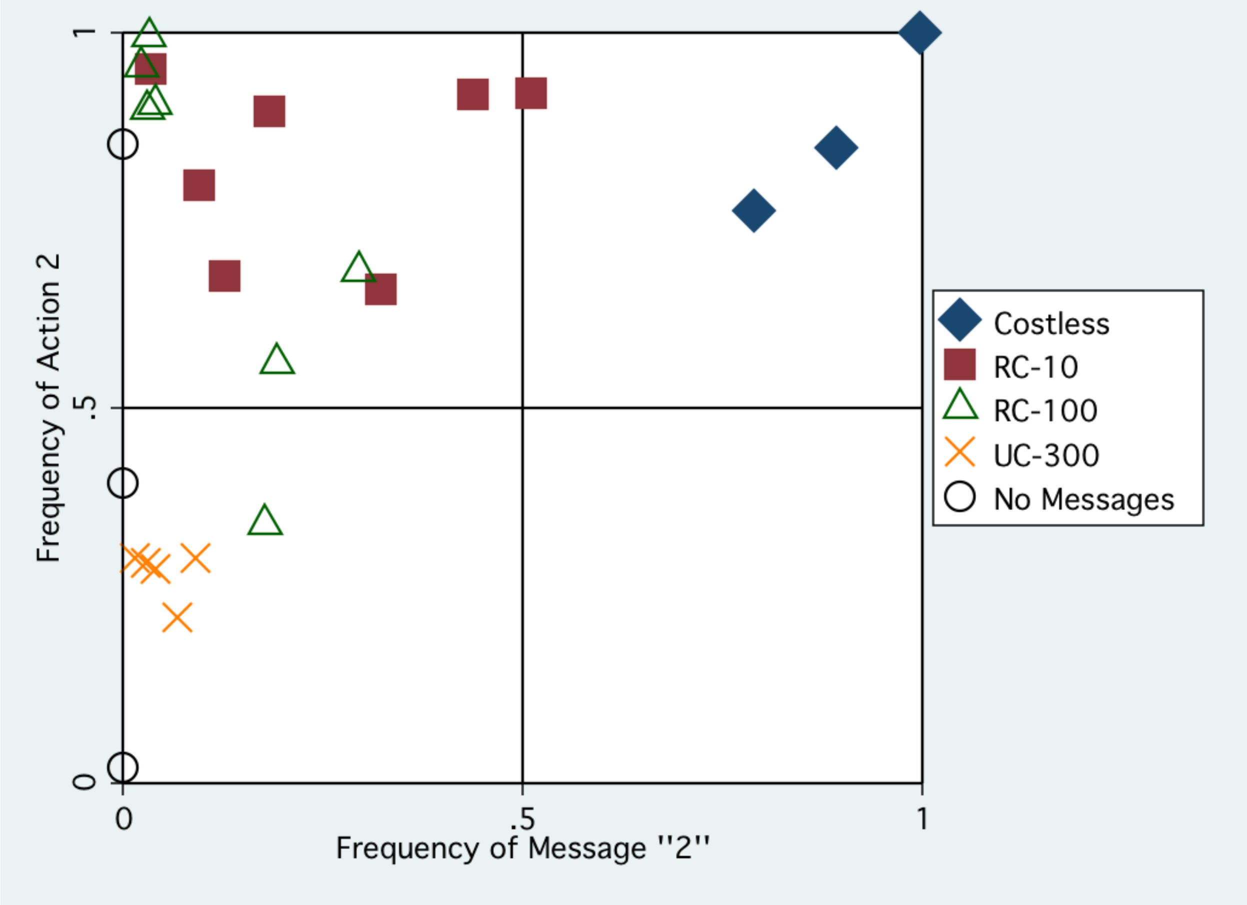

Figure 5: Message and Action Frequencies by Session

Appendices

Pre-Play Communication with Forgone Costly Messages: Experimental Evidence on Forward Induction

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Appendix A: Theoretical Background

In this appendix we verify our claim that efficient play in the subgame without communication is the unique pure-strategy equilibrium outcome that passes Gonvindan and Wilson's (2009) FI test in the communication game with reasonable message costs. In addition we show that a variety of solution concepts that capture forward induction reasoning without reference to Nash equilibrium have little or no predictive power in our environment. This is the basis for our assertion that our experiment helps to differentiate empirically between formalizations of the forward-induction idea.

In our analysis, without loss of generality we will lump together strategies of a player that differ only at information sets ruled out by that player's strategy; e.g. if a player's strategy specifies sending a message, we will not explicitly keep track of that player's continuation play in the event that he does not send a messages. All the strategies that we group together are outcome equivalent and indistinguishable by opponents and outside observers. The only effect of carrying the distinction along would be to increase notational burden. In our game with two

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costly messages, the option of not sending a message, and two choices at the action stage, each player has 3×2^9 strategies before and 24 strategies after grouping together outcome-equivalent strategies.

Before applying Govindan and Wilson’s forward induction (GW-FI) test to our game, we briefly recall the limited power of Iterative Admissibility (IA), Extensive Form Rationalizability (EFR), and Fully Permissible Sets (FPS) when two players have the option to burn money. To keep this part of the analysis tractable we conduct it for the one-message game where each player has exactly one costly message; later, when we return to applying GW-FI, we do so for the two-message game where each player has two costly messages as in our experiment. In the one-message game, a player who uses strategy *Mij* sends a message, takes action *i* if he receives a message and takes action *j* if he does not receive a message. Similarly *Nij* stands for the strategy of not sending a message, responding to a message with action *i* and taking action *j* if no message is received. For convenience, Table A.1. reports the payoffs from all resulting combinations of these strategies.

Table A.1: Communication Game with One Costly Message

	M22	M21	M12	M11	N22	N21	N12	N11
M22	1000-c, 1000-c	1000-c, 1000-c	-c, 800-c	-c, 800-c	1000-c, 1000	1000-c, 1000	-c, 800	-c, 800
M21	1000-c, 1000-c	1000-c, 1000-c	-c, 800-c	-c, 800-c	800-c, 0	800-c, 0	800-c, 800	800-c, 800
M12	800-c, -c	800-c, -c	800-c, 800-c	800-c, 800-c	1000-c, 1000	1000-c, 1000	-c, 800	-c, 800
M11	800-c, -c	800-c, -c	800-c, 800-c	800-c, 800-c	800-c, 0	800-c, 0	800-c, 800	800-c, 800
N22	1000, 1000-c	0, 800-c	1000, 1000-c	0, 800-c	1000, 1000	0, 800	1000, 1000	0, 800
N21	1000, 1000-c	0, 800-c	1000, 1000-c	0, 800-c	800, 0	800, 800	800, 0	800, 800
N12	800, -c	800, 800-c	800, -c	800, 800-c	1000, 1000	0, 800	1000, 1000	0, 800
N11	800, -c	800, 800-c	800, -c	800, 800-c	800, 0	800, 800	800, 0	800, 800

This is the reduced strategic form of the game in which players have a choice between sending a message, M, and not sending a message, N. A strategy Mij prescribes sending a message, M, taking action i if the opponent sent a message and action j if the opponent did not send a message. A strategy Nij prescribes not sending a message, N, taking action i if the opponent sent a message and action j if the opponent did not send a message. In each cell the entry in the Northwest corner is the row player’s payoff and the entry in the Southeast corner is the column player’s payoff. The cost of sending a message is indicated by c.

Informally, players in a game use forward induction when they seek to predict another player's future behavior by rationalizing his past actions. There are two strands in the literature that formalize this idea, one that references equilibrium outcomes and one that does not.
The non-equilibrium literature on forward induction starts with Pearce's (1984) introduction of the extensive-form rationalizability condition (EFR). The key idea is that a player will not use a strategy that fails to be a best response to all beliefs at an information set reached by that strategy. Strategies that do not pass this test are eliminated and the test is repeated on the reduced set of strategies until the process converges (to the EFR set).

EFR has forward induction implications because, at a given information set, it restricts the beliefs of the player moving there about strategies of others in accordance with their rationality.[1] The conditions on players' rationality and beliefs that give rise to EFR and related notions of iterated dominance have been clarified by the epistemic game theory literature. In particular, Battigalli and Siniscalchi (2002) show that EFR corresponds to *rationality and common strong belief in rationality* on complete type spaces. A similar characterization is available for iterative admissibility (IA), where in each round all weakly dominated strategies of all players are deleted; m+1 rounds of iterative deletion of weakly dominated strategies corresponds to *rationality and m-th order assumption of rationality* with complete type structures (Brandenburger, Friedenberg and Keisler, 2008). Finally, Asheim & Dufwenberg (2003) propose their notion of fully permissible sets (FPS), which in general neither implies nor is implied by IA or EFR, despite underlying assumptions that rule out weakly dominated strategies.

EFR, IA, and FPS come to the same conclusion for the one-message game. All three rule out the strictly dominated strategy M11 of sending a costly signal and then unconditionally playing action 1, and no more. Ben-Porath and Dekel (1992) already noted this coarseness of the IA prediction in money-burning games where more than one player has the option to burn money. For the sake of completeness we include proofs of all three claims for our game.

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[1] A classical example of the power of this idea is its application to the battle of the sexes with an outside option: Player 1 has the choice between an outside option with a common payoff of 2 and entering a "battle of the sexes" with payoff pairs (3,1) and (1,3) at the two pure-strategy equilibria and (0,0) otherwise. Player 1's strategy of opting in and then playing for (1,3) is strictly dominated. Hence, if Player 2 is called upon to move he must believe Player 1 aims for (3,1). Given those restricted beliefs the strategy that might have given Player 2 a payoff of 3 is no longer a best reply and it is uniquely optimal for him to play according to the (3,1) equilibrium in the continuation game. As a result, Player 1 opts in and the forward-induction equilibrium payoff pair is (3,1).

Claim. *In the game where both players have a single costly message, with the exception of the strategy of sending a message and then taking action 1 unconditionally (M11), all pure strategies belong to the set of iteratively admissible (IA) strategies.*

Proof: We will check one by one that none of the remaining pure strategies are (weakly) dominated by either a pure or a mixed strategy, both before and after the strictly dominated strategy M11 is eliminated. Since the arguments for both cases are exactly the same, we will not explicitly distinguish them.

For N11 to be dominated, it has to be dominated by N21, the only other best reply against N11. But N21 does strictly worse against M21.

For N12 to be dominated, it has to be dominated by N22, the only other best reply against N22. But N22 does strictly worse against M21.

For N21 to be dominated, it has to be dominated by N22, the only other best reply against M12. But N22 does strictly worse against N21.

For N22 to be dominated, it has to be dominated by N21, the only other best reply against M22. But N21 does strictly worse against N22.

For M12 to be dominated, it has to be dominated by M22, the only other best reply against N21. But M22 does strictly worse against M12.

For M21 to be dominated, it has to be dominated by M22, the only other best reply against M21. But M22 does strictly worse against N12.

For M22 to be dominated, it has to be dominated by M21, the only other best reply against M21. But M21 does strictly worse against N22. **QED**

Claim. *In the game where both players have a single costly message, with the exception of the strategy of sending a message and then taking action 1 unconditionally (M11), all pure strategies belong to the set of extensive-form rationalizable (EFR) strategies.*

Proof: It suffices to construct for each pure strategy *S* that remains after M11 is removed and for every information set that is not ruled out by *S* a conjecture whose support does not include M11 and for which the strategy *S* is a best reply at that information set. Note that at an information set that is reached given the initial conjecture, the conjecture has to remain unchanged. We will use only conjectures that assign probability one to a pure strategy. It then suffices for every strategy *S* to specify an initial conjecture C_S and a conjecture for the information set that is reached when C_S is proved wrong. Denote this alternative conjecture by C_A; if, for example, a player initially conjectures that the other will send a message, he will need an alternative conjecture for the event that he does not receive a message. Accordingly we will list for each strategy S a triple (S; C_S, C_A). One checks immediately that in the following list of such triples the strategy S is a best reply at the appropriate information sets: (M22; M21, N21), (M21; M21, N12),(M12; N21, M12), (N22; N22, M22), (N21; M12, N11), (N12; N12, M21), (N11; N11, M21). **QED**

Claim. *In the game where both players have a single costly message, with the exception of the strategy of sending a message and then taking action 1 unconditionally (M11), all pure strategies belong to a fully permissible set.*

Proof: We will not reproduce Asheim & Dufwenberg's (2003) definitions here. Suffice it to note that (as easily inferred via their paper) if we can find for each player a non-empty subset of strategies such that each contained strategy is neither weakly dominated nor weakly dominated given that the opponents are restricted to choose from their subsets, then each player's subset is fully permissible. Applied to Table A.1., we infer that for either player {M22, M21, M12, N22, N21, N12, N11} is fully permissible (as seen if we pick that subset for each player). The veracity of the claim is implied. **QED**

Note that, in particular, EFR (IA, FPS) does not rule out the outcome where no messages are sent and both take action 1. This is because sending a costly message and then playing action 1 is rational if it was done in the hope that the other player would also send a message but that message is not forthcoming. Therefore a player who observes the other player sending a message may nevertheless rationally believe that that player will take action 1. When both players have the option of sending a message, messages can be viewed as conditional statements. Sending a message may then be an offer of conditional cooperation: "I will take action 2 provided you send a message as well." In contrast, as we will see, with an approach that emphasizes the role of a equilibrium outcome, a player who sends an off-equilibrium-path message has no expectation of the other player sending a message as well. Since the other player's actions are pinned down by the equilibrium, his messages are unconditional and can be interpreted using equilibrium dominance: The deviating player expects at least as much from his deviation as from the reference equilibrium.

This equilibrium refinement approach to forward induction dates back to Kohlberg and Mertens (KM) (1986). They coined the term and in their Proposition 6 associated it with the property of stable sets of equilibria containing stable sets of games obtained by removing strategies that are not best replies to any of the equilibria in the set. KM did not formally define forward induction. For this reason and for its ease of applicability we use Govindan and Wilson's (2009) closely related definition (hereafter referred to as GW-FI).

We apply GW-FI to the two-message game that we used in our experiment. Recall that we do not distinguish a player's strategies that differ only in behavior at information sets that are precluded by those strategies. Then, a strategy μijk with $\mu \in \{M_1, M2\ \ , N\}$ and $i, j, k \ \in \{1,2\}$ specifies the choice of message (or none) μ, the response i to message M_1, the response j to message M_2 and the response k to no message, N.

Govindan and Wilson (2009) define forward induction in terms of Reny's (1992) "weak sequential equilibrium." Weak sequential equilibrium coincides with Kreps and Wilson's (1982) sequential equilibrium, except that a player's strategy need not prescribe best replies at information sets that are ruled out by that strategy. GW use a variant of weak sequential equilibrium in which beliefs at an information set are distributions over other players' strategies rather than over nodes in that information set.

Recall that an equilibrium outcome in a game is the distribution over terminal nodes induced by the strategies that support that equilibrium. The key concept in GW's definition of FI is that of a ***relevant strategy***: A pure strategy is relevant for the outcome of a game if there exists a weakly sequential equilibrium with that outcome such that the strategy is a best reply to equilibrium beliefs at every information set not excluded by that strategy. An information set is relevant for an outcome provided that not every combination of strategies relevant for that outcome precludes it. The forward induction requirement then asks that at relevant information sets beliefs be concentrated on relevant strategies.

Definition. (Govindan and Wilson, 2009) *An outcome satisfies* ***forward induction*** *if it results from a weakly sequential equilibrium in which at every information set that is relevant for that* *outcome the support of the belief of the player acting there is confined to profiles of Nature's strategies and other players' strategies that are relevant for that outcome.*

The following result classifies all pure-strategy equilibrium outcomes in the two-message game according whether or not they satisfy forward induction.

Claim. *In the game where each player has the option to either send no message,* $\boldsymbol{N}$*, or one of two costly messages,* $\boldsymbol{M_1}$ *and* $\boldsymbol{M_2}$*, (1) the equilibrium outcome* $\boldsymbol{NN}$**-1** *in which players send no message and take action 1 fails to satisfy forward induction; (2) the equilibrium outcomes* $\boldsymbol{M_r M_s}$***-2*** *with* $r, s = 1{,}2$ *in which players send message* $\boldsymbol{M_r}$ *and* $\boldsymbol{M_s}$ *respectively and take action 2 fail to satisfy forward induction; (3) the equilibrium outcomes* $\boldsymbol{NM_s}$**-2** and $\boldsymbol{M_s N}$**-2**, s=1,2, *in which exactly one player sends a message and both take action 2 fail to satisfy forward induction; and, (4) the equilibrium outcome* $\boldsymbol{NN}$**-2** *in which players send no message and take action 2 satisfies forward induction.*

Proof: (1) The $\boldsymbol{NN}$**-1** outcome is supported by the set of mixtures of strategies *Nij1, i,j=1,2,* that assign probabilities p_{Nij1} to those strategies that satisfy

$$p_{N211} + p_{N221} \leq \frac{800 + c}{1000}\text{, and} \qquad (1)$$

$$p_{N121} + p_{N221} \leq \frac{800 + c}{1000}\,. \qquad (2)$$

The set of strategies that is relevant for this outcome is $\{Nij1, M_1ij2, M_2ij2\}_{i,j=1,2}$. Hence, at the (relevant) information set of player 1 where player 1 unexpectedly observes player 2 having sent message M_2, GW-FI requires us to restrict player 1's beliefs over player 2's strategies to the set $\{M_2ij2\}_{i,j=1,2}$. Against such beliefs neither *N111* nor *N211* are best replies. Therefore all best replies of player 1 that satisfy the GW-FI belief restriction violate condition (2).

(2) The $\boldsymbol{M_1 M_2}$***-2*** outcome (which we examine representatively for all $\boldsymbol{M_r M_s}$***-2*** equilibrium outcomes) is supported by mixtures over player 1's strategies $M_1 i2k,$ with $i, k = 1{,}2$ that satisfy

$$p_{M_1 122} + p_{M_1 222} \leq \frac{1000 - c}{1000} \qquad (3)$$

and by mixtures over player 2's strategies $M_2 2jk,$ with $j, k = 1{,}2$ that satisfy

$$p_{M_2212} + p_{M_2222} \leq \frac{1000 - c}{1000} . \qquad (4)$$

The set of player 2's strategies that is relevant for this outcome is $\{N2jk, M_12jk, M_22jk\}_{j,k=1,2}$. Hence, at the (relevant) information set of player 1 where player 1 unexpectedly observes player 2 not having sent a message, GW-FI requires us to restrict player 1's beliefs over player 2's strategies to the set $\{N2jk\}_{j,k=1,2}$. Any mixture over player 1's strategies M_1i2k, with $i, k = 1,2$, that is a best reply to such beliefs must satisfy $p_{M_1121} = p_{M_1221} = 0$ and therefore $p_{M_1122} + p_{M_1222} = 1$, in violation of condition (3).

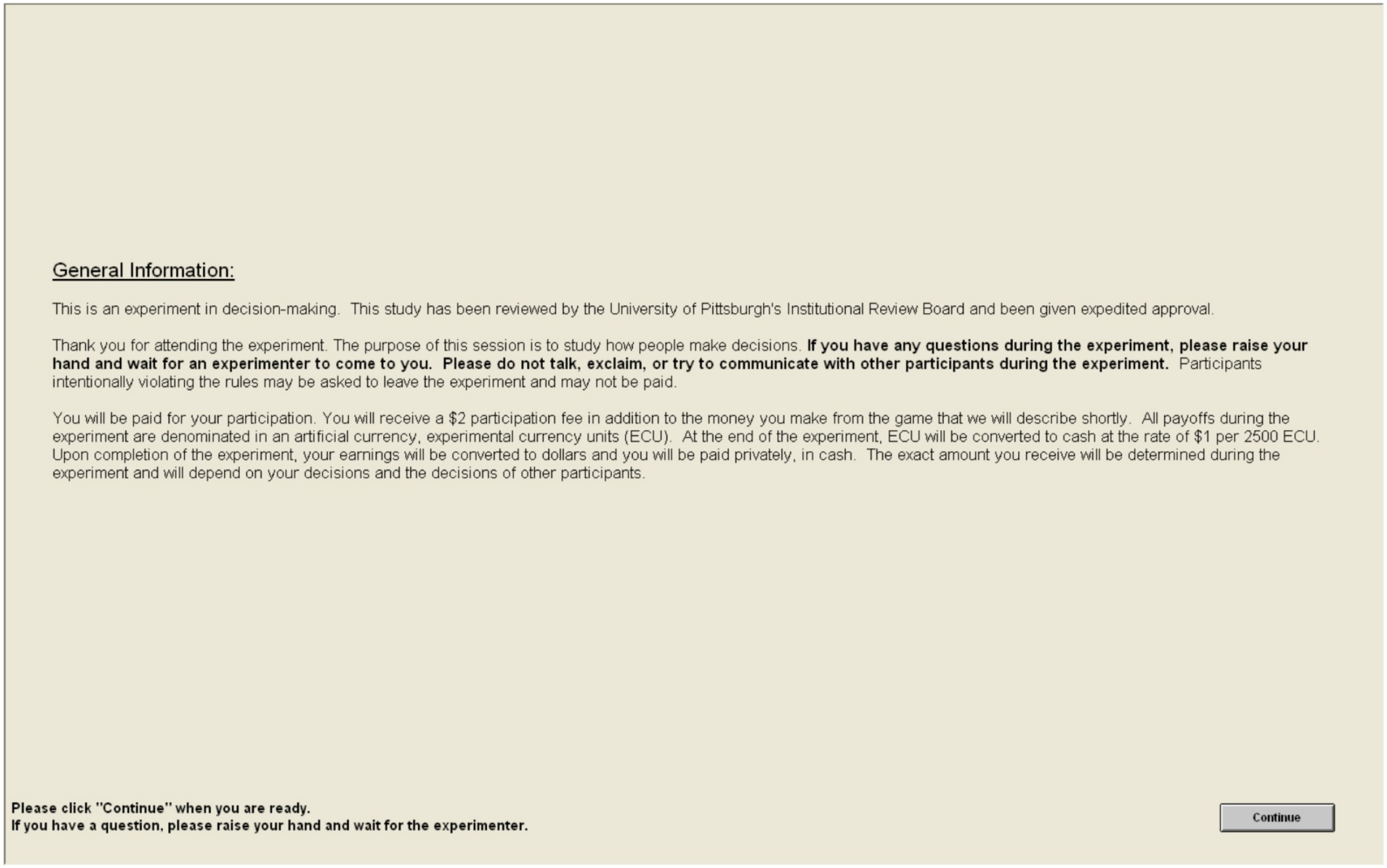
(3) The ***NM*$_2$-2** outcome (which we examine representatively for all ***NM$_s$*-*2*** and ***M$_s$N*-*2*** equilibrium outcomes, s=1,2) is supported by arbitrary mixtures of player 2 over strategies in the set $\{M_2ij2\}_{i,j=1,2}$ and by mixtures of player 1 over strategies in the set $\{Ni2k\}_{i,k=1,2}$ that satisfy the condition

$$p_{N122} + p_{N222} \leq \frac{1000 - c}{1000} . \qquad (5)$$

The set of strategies of player 2 that is relevant for this outcome is $\{Nij2, M_1ij2, M_2ij2\}_{i,j=1,2}$. Consider the relevant information set of player 1 who has followed his equilibrium strategy, not sent a message and who has observed a deviation by player 2 to not sending a message. GW-FI requires us to restrict the support of player 1's beliefs at this information set to the set of strategies $\{Nij2\}_{i,j=1,2}$. Against such beliefs, however, no strategy of player 1 that assigns positive probability to any of the strategies in the set $\{Ni21\}_{i,j=1,2}$ is a best reply. Any mixture over player 1's strategies $Ni2k$, with $i, k = 1,2$, that is a best reply to such beliefs must satisfy $p_{N121} = p_{N221} = 0$ and therefore $p_{N122} + p_{N222} = 1$, in violation of condition (5).

(4) The equilibrium outcome ***NN*-2** is supported by arbitrary mixtures over strategies in the set $\{Nij2\}_{i,j=1,2}$. These strategies are also the relevant strategies. Hence the only relevant information sets for this outcome are the ones where neither player has sent a message. Since they are on the equilibrium path, the belief restriction has no bite. **QED**

Appendix B: Instructions (RC-10 Condition)



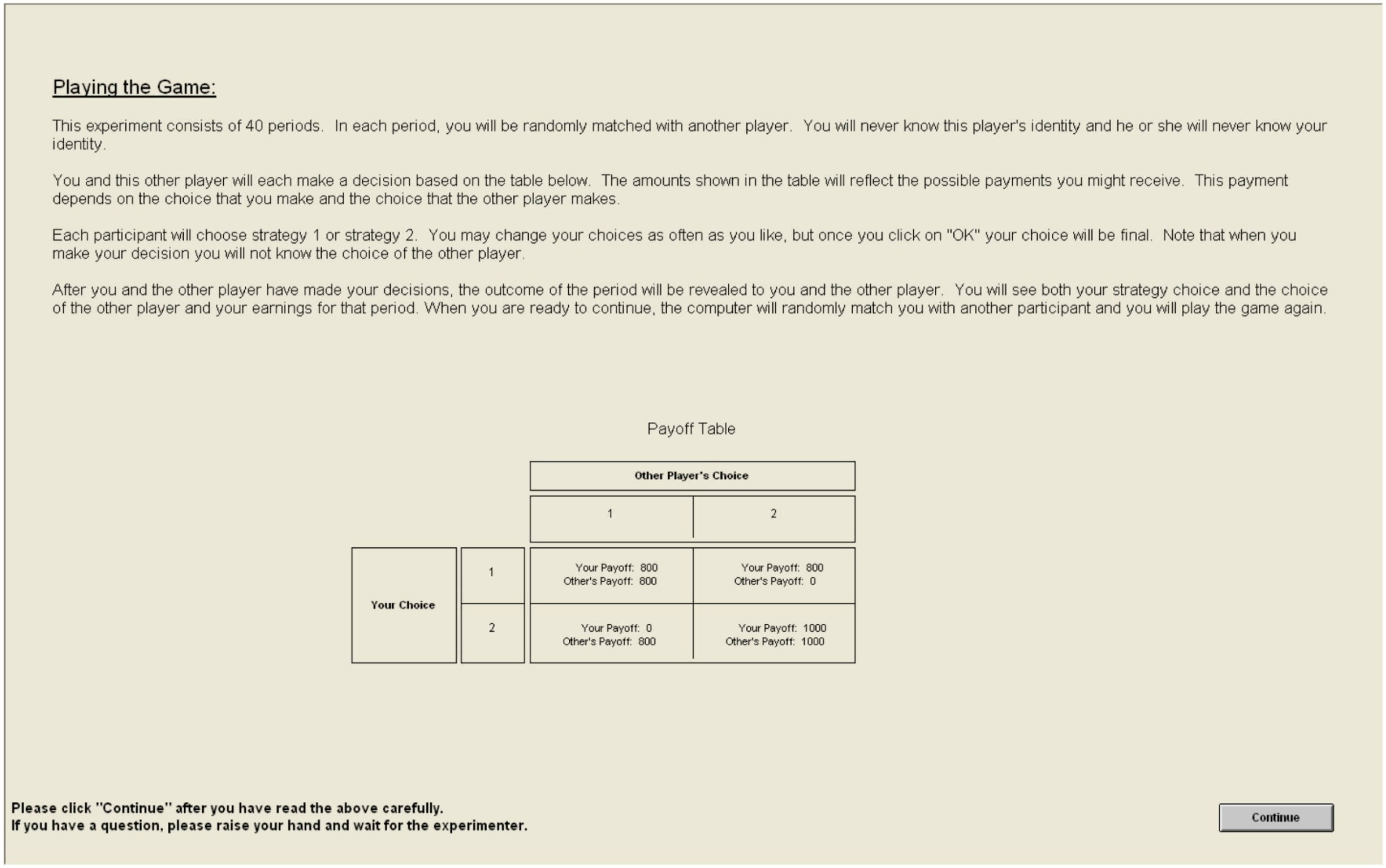
General Information:

This is an experiment in decision-making. This study has been reviewed by the University of Pittsburgh's Institutional Review Board and been given expedited approval.

Thank you for attending the experiment. The purpose of this session is to study how people make decisions. **If you have any questions during the experiment, please raise your hand and wait for an experimenter to come to you. Please do not talk, exclaim, or try to communicate with other participants during the experiment.** Participants intentionally violating the rules may be asked to leave the experiment and may not be paid.

You will be paid for your participation. You will receive a $2 participation fee in addition to the money you make from the game that we will describe shortly. All payoffs during the experiment are denominated in an artificial currency, experimental currency units (ECU). At the end of the experiment, ECU will be converted to cash at the rate of $1 per 2500 ECU. Upon completion of the experiment, your earnings will be converted to dollars and you will be paid privately, in cash. The exact amount you receive will be determined during the experiment and will depend on your decisions and the decisions of other participants.

Please click "Continue" when you are ready.
If you have a question, please raise your hand and wait for the experimenter.



Playing the Game:

This experiment consists of 40 periods. In each period, you will be randomly matched with another player. You will never know this player's identity and he or she will never know your identity.

You and this other player will each make a decision based on the table below. The amounts shown in the table will reflect the possible payments you might receive. This payment depends on the choice that you make and the choice that the other player makes.

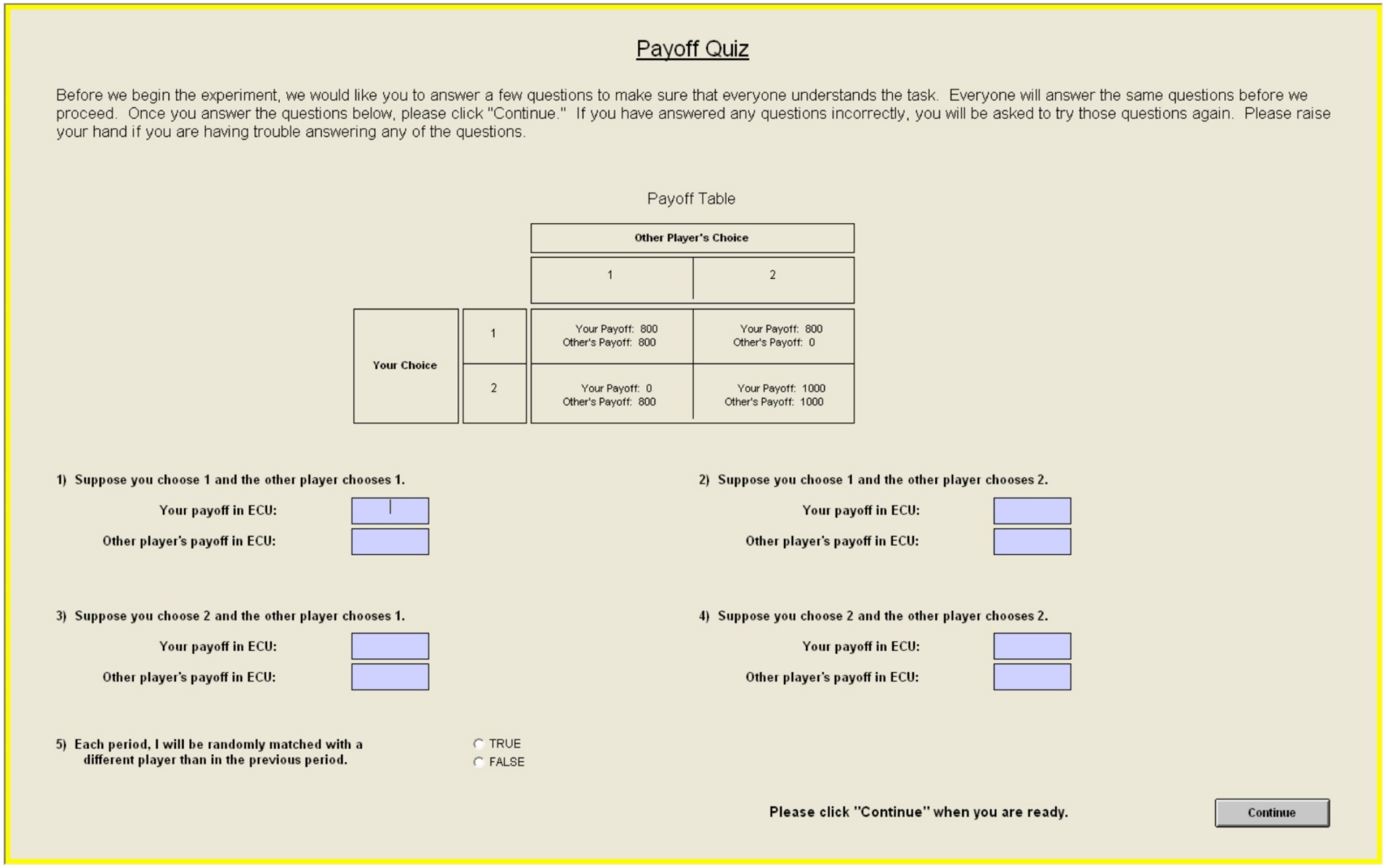
Each participant will choose strategy 1 or strategy 2. You may change your choices as often as you like, but once you click on "OK" your choice will be final. Note that when you make your decision you will not know the choice of the other player.

After you and the other player have made your decisions, the outcome of the period will be revealed to you and the other player. You will see both your strategy choice and the choice of the other player and your earnings for that period. When you are ready to continue, the computer will randomly match you with another participant and you will play the game again.

Payoff Table

		Other Player's Choice	
		1	2
Your Choice	1	Your Payoff: 800 Other's Payoff: 800	Your Payoff: 800 Other's Payoff: 0
	2	Your Payoff: 0 Other's Payoff: 800	Your Payoff: 1000 Other's Payoff: 1000

Please click "Continue" after you have read the above carefully.
If you have a question, please raise your hand and wait for the experimenter.



Payoff Quiz

Before we begin the experiment, we would like you to answer a few questions to make sure that everyone understands the task. Everyone will answer the same questions before we proceed. Once you answer the questions below, please click "Continue." If you have answered any questions incorrectly, you will be asked to try those questions again. Please raise your hand if you are having trouble answering any of the questions.

Payoff Table

		Other Player's Choice	
		1	2
Your Choice	1	Your Payoff: 800 Other's Payoff: 800	Your Payoff: 800 Other's Payoff: 0
	2	Your Payoff: 0 Other's Payoff: 800	Your Payoff: 1000 Other's Payoff: 1000

1) Suppose you choose 1 and the other player chooses 1.

Your payoff in ECU:

Other player's payoff in ECU:

2) Suppose you choose 1 and the other player chooses 2.

Your payoff in ECU:

Other player's payoff in ECU:

3) Suppose you choose 2 and the other player chooses 1.

Your payoff in ECU:

Other player's payoff in ECU:

4) Suppose you choose 2 and the other player chooses 2.

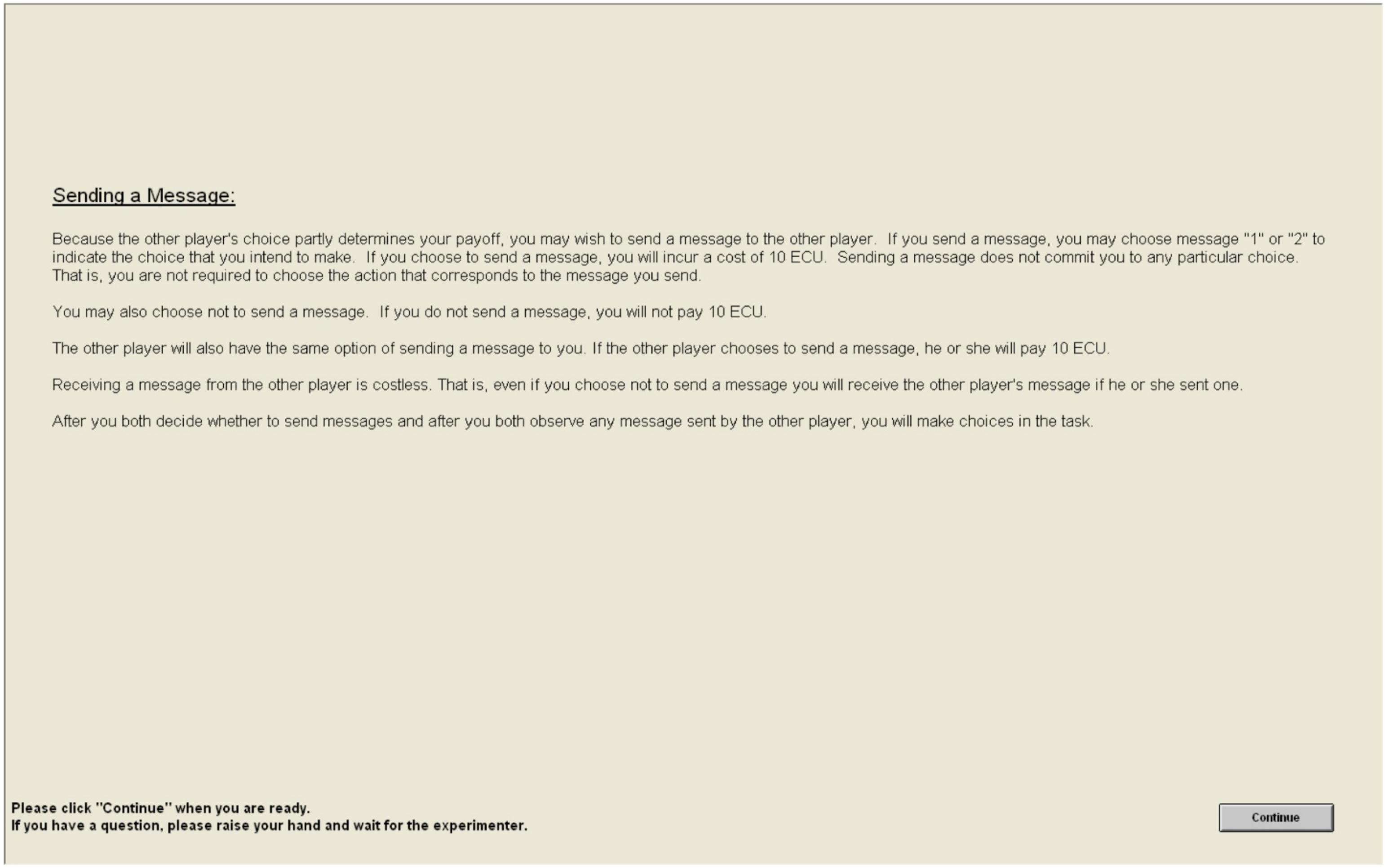
Your payoff in ECU:

Other player's payoff in ECU:

5) Each period, I will be randomly matched with a different player than in the previous period.

○ TRUE
○ FALSE

Please click "Continue" when you are ready.



Sending a Message:

Because the other player's choice partly determines your payoff, you may wish to send a message to the other player. If you send a message, you may choose message "1" or "2" to indicate the choice that you intend to make. If you choose to send a message, you will incur a cost of 10 ECU. Sending a message does not commit you to any particular choice. That is, you are not required to choose the action that corresponds to the message you send.

You may also choose not to send a message. If you do not send a message, you will not pay 10 ECU.

The other player will also have the same option of sending a message to you. If the other player chooses to send a message, he or she will pay 10 ECU.

Receiving a message from the other player is costless. That is, even if you choose not to send a message you will receive the other player's message if he or she sent one.

After you both decide whether to send messages and after you both observe any message sent by the other player, you will make choices in the task.

Please click "Continue" when you are ready.
If you have a question, please raise your hand and wait for the experimenter.

Appendix C: Additional Analysis

Table C.1A. Comparisons of Messages and Choices Early and Late in Experiment (Periods 1 vs. 40)

	Costless	RC-10	RC-100	UC-300	No Messages
Message 2 (Period 1)	83%	34%	14%	2%	
Message 2 (Period 40)	90%	31%	17%	3%	
	$z = 0.76$ $p = 0.45$	$z = 0.36$ $p = 0.72$	$z = 0.46$ $p = 0.64$	$z = 0.59$ $p = 0.56$	
Choice 2 (Period 1)	90%	79%	80%	56%	53%
Choice 2 (Period 40)	83%	84%	83%	6%	33%
	$z = 0.76$ $p = 0.45$	$z = 0.87$ $p = 0.38$	$z = 0.43$ $p = 0.66$	$z = 5.41$ $p < 0.001$	$z = 1.56$ $p = 0.12$

Note: statistical tests of binomial proportions

Table C.1B. Comparisons of Messages and Choices Early and Late in Experiment (Periods 1-10 vs. 31-40)

	Costless	RC-10	RC-100	UC-300	No Messages
Message 2 (Period 1)	88%	25%	10%	4%	
Message 2 (Period 40)	89%	28%	14%	5%	
	$t_{58} = 0.14$ $p = 0.89$	$t_{138} = 0.60$ $p = 0.55$	$t_{138} = 0.89$ $p = 0.37$	$t_{98} = 0.20$ $p = 0.84$	
Choice 2 (Period 1)	91%	82%	74%	52%	52%
Choice 2 (Period 40)	83%	83%	80%	9%	30%
	$t_{58} = 1.26$ $p = 0.21$	$t_{138} = 0.06$ $p = 0.95$	$t_{58} = 1.18$ $p = 0.24$	$t_{98} = 7.14$ $p < 0.001$	$t_{58} = 1.87$ $p = 0.07$

Note: statistical tests of mean frequency (by subject)

Table C.2: Random-effects Probit Regressions of Message “2” Use

Dependent variable: *Subject sent message “2”*	All periods		Period 1	Periods 2 - 40
	(1)	(2)	(3)	(4)
Reasonably Costly Messages (RC-10)	-4.384^{***} (0.404)	-4.410^{***} (0.441)	-1.372^{***} (0.313)	-4.669^{***} (0.417)
Reasonably Costly Messages (RC-100)	-5.165^{***} (0.400)	-5.218^{***} (0.438)	-2.035^{***} (0.329)	-5.442^{***} (0.409)
Unreasonably Costly Messages (UC-300)	-5.891^{***} (0.419)	-5.777^{***} (0.464)	-3.021^{***} (0.492)	-6.086^{***} (0.429)
Period		0.006 (0.008)		
Period X Reasonably Costly Messages (RC-10)		0.001 (0.009)		
Period X Reasonably Costly Messages (RC-100)		0.002 (0.009)		
Period X Unreasonably Costly Messages (UC-300)		-0.006 (0.010)		
Opponent in previous period sent message “2”				0.163^{**} (0.069)
Constant	2.771^{***} (0.323)	2.662^{***} (0.361)	0.967^{***} (0.272)	2.882^{***} (0.332)
Observations	8,800	8,800	220	8,580
Number of subjects	220	220	220	220
Log Likelihood	-1884.94	-1880.18	-92.13	-1783.67

All models include data from all conditions with messages; models 1, 2, 4 and 5 include subject random effects
Standard errors in parentheses; * - $p < 0.1$; ** - $p < 0.05$; *** - $p < 0.01$

Table C.3: Random-effects Probit Regressions of Action Choice 2 in Stag-Hunt Subgame

Dependent variable: Subject chose action 2	All periods			Period 1	Period 1 & no messages
	(1)	(2)	(3)	(4)	(5)
Costless Messages	2.346^{***}	2.115^{***}	0.746^{*}	1.198^{***}	
	(0.390)	(0.450)	(0.453)	(0.387)	
Reasonably Costly Messages (RC-10)	2.132^{***}	1.261^{***}	1.997^{***}	0.708^{**}	0.591^{*}
	(0.328)	(0.368)	(0.367)	(0.284)	(0.345)
Reasonably Costly Messages (RC-100)	1.735^{***}	0.649^{*}	1.602^{***}	0.758^{***}	0.664^{**}
	(0.327)	(0.366)	(0.365)	(0.286)	(0.310)
Unreasonably Costly Messages (UC-300)	-0.353	-0.003	-0.480	0.067	0.136
	(0.341)	(0.383)	(0.381)	(0.290)	(0.295)
Period		-0.046^{***}			
		(0.005)			
Period X Costless Messages		0.020^{**}			
		(0.008)			
Period X RC-10		0.049^{***}			
		(0.006)			
Period X RC-100		0.059^{***}			
		(0.006)			
Period X UC-300		-0.023^{***}			
		(0.007)			
Received Message “2” (Costless Messages)			2.366^{***}		
			(0.198)		
Received Message “2” X RC-10			-0.848^{***}		
			(0.233)		
Received Message “2” X RC-100			-0.173		
			(0.250)		
Received Message “2” X UC-300			-0.745^{***}		
			(0.249)		
Constant	-0.415	0.456	-0.435	0.084	0.084
	(0.272)	(0.308)	(0.304)	(0.229)	(0.229)
Observations	10,000	10,000	10,000	250	148
Number of subjects	250	250	250	250	148
Log Likelihood	-3500.49	-3233.64	-3096.57	-136.18	-91.24

Models 1 through 4 include data from all conditions; model 5 omits Costless Messages condition; models 1 through 3 include subject random effects.

Standard errors in parentheses; * - $p < 0.1$; ** - $p < 0.05$; *** - $p < 0.01$

Figure C.1a: Frequency of Message 2 and Action 2 by Session (No Messages)

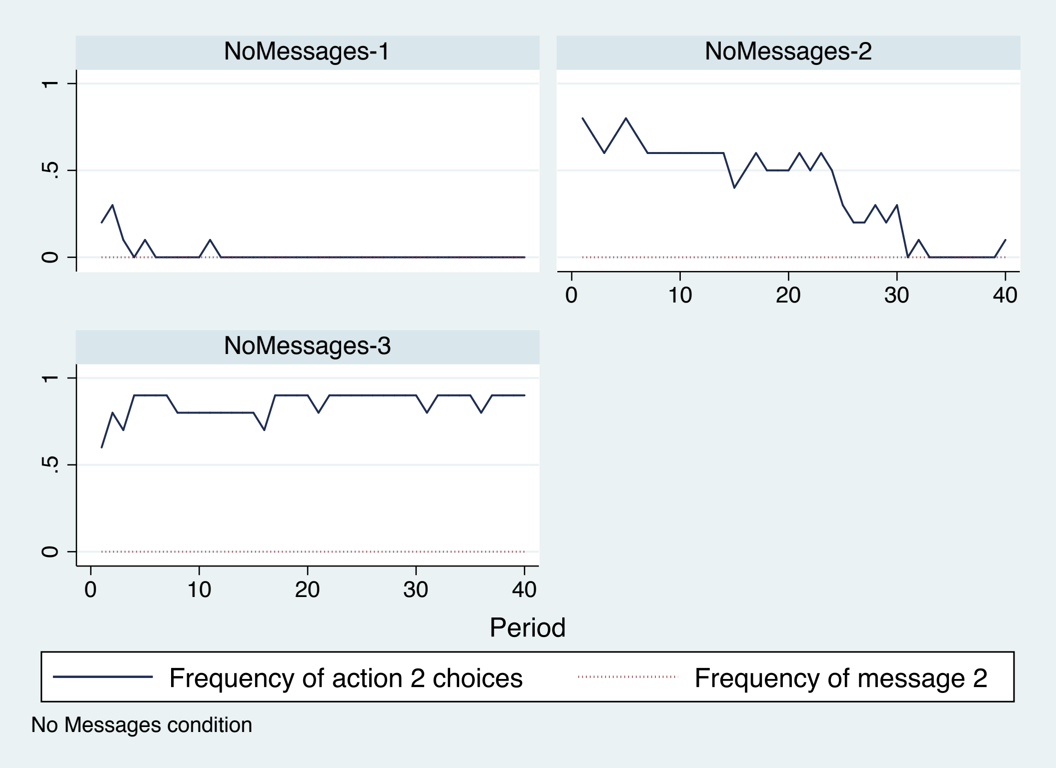


Figure C.1b: Frequency of Message 2 and Action 2 by Session (Costless Messages)

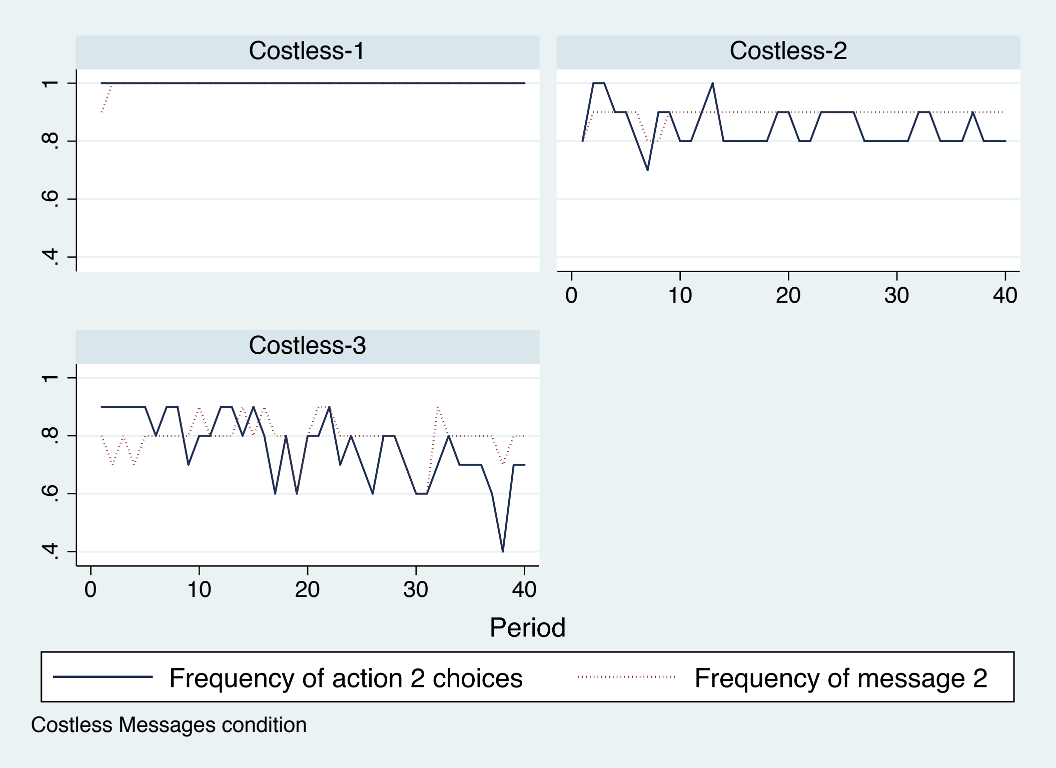
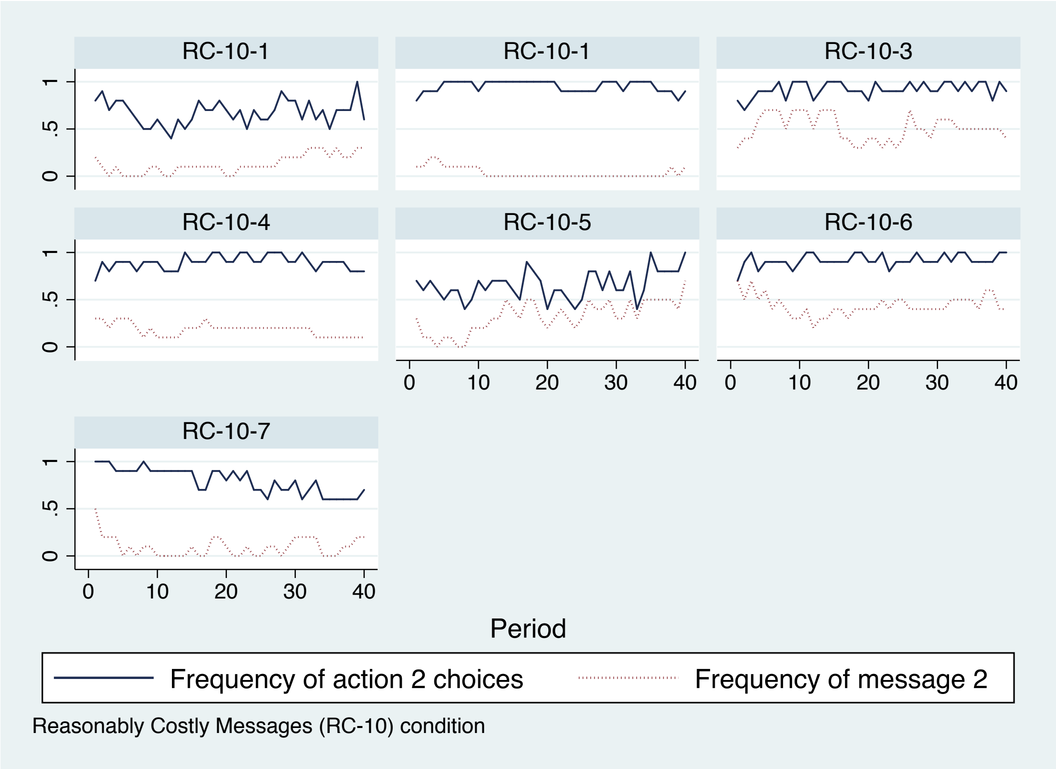
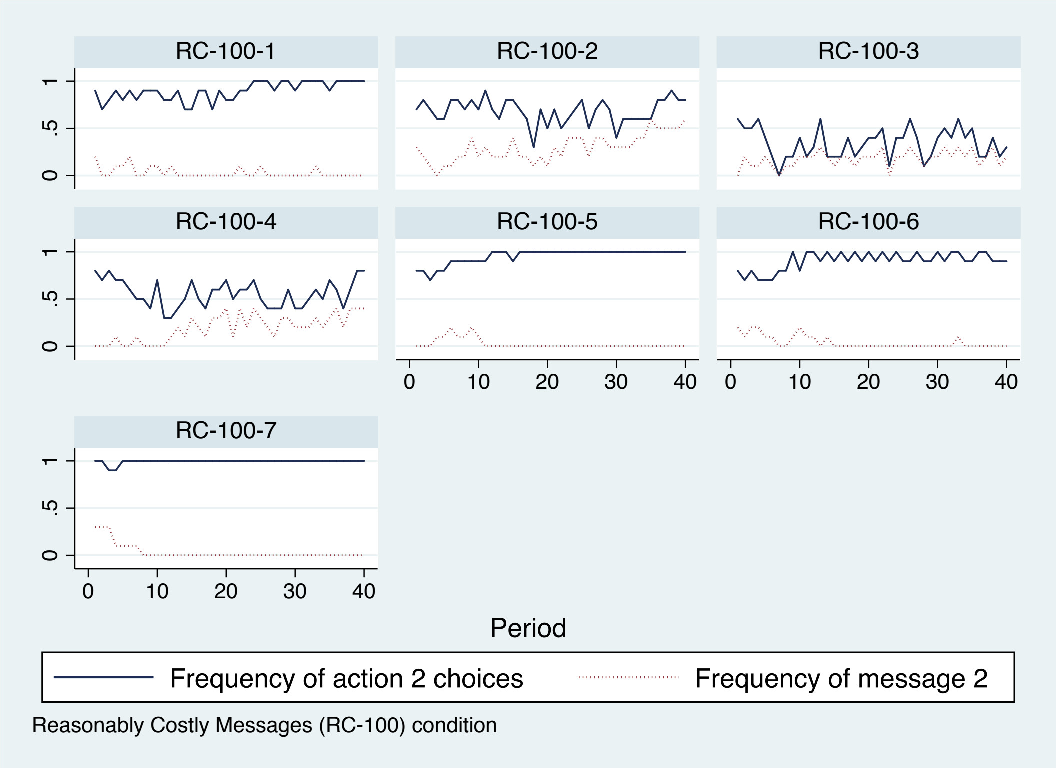


Figure C.1c: Frequency of Message 2 and Action 2 by Session (RC-10)



Reasonably Costly Messages (RC-10) condition

Figure C.1d: Frequency of Message 2 and Action 2 by Session (RC-100)



Reasonably Costly Messages (RC-100) condition

Figure C.1e: Frequency of Message 2 and Action 2 by Session (UC-300)