University of Zurich

Department of Economics

Working Paper Series

ISSN 1664-7041 (print)
ISSN1664-705X(online)

Working Paper No. 34

Coordination, Efficiency and Pre-Play Communication with Forgone Costly Messages

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October 2011

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August 12, 2011*

We examine communication in a two-player coordination game with Pareto-ranked equilibria. Prior research demonstrates that efficient coordination is difficult without communication but obtains regularly with (mandatory) costless pre-play messages. In a laboratory experiment, we introduce two realistic features of communication by making the sending of messages optional and costly. Even small costs dramatically reduce message use, but efficient coordination of actions occurs with similar frequency to that observed under costless communication. By varying communication costs we corroborate several predictions from a theoretical analysis based on forward induction. Our results indicate that, for some levels of communication costs, explicit communication may be unnecessary for efficient coordination; instead, players simply need to know that the option to send messages was available. Thus, the relationship between communication and coordination is more complex than suggested by prior research.

JEL Codes: C72, C92, D83

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I. Introduction

An extensive literature on coordination games explores the conditions under which independent agents can efficiently coordinate their actions. Much of this research consists of laboratory experiments that identify varying conditions under which players select an efficient equilibrium from a set of multiple possible equilibrium outcomes (for reviews, see Camerer (2003, Chapter 7) and Devetag & Ortmann (2007)).

One commonly investigated type of coordination game involves a tradeoff between equilibria that are efficient and those that provide greater payoff security (Van Huyck, et al., 1990; Cooper et al., 1990). For example, the two-player coordination game in Table 1, studied by Cooper et al. (1992) and often referred to as the "stag hunt" game, has this property. The two pure-strategy Nash equilibria of the game are a payoff-dominant one (2,2) that yields the highest possible payoff for both players and a risk-dominant one (1,1) that obtains by players selecting the action that yields both the highest minimum payoff and the highest payoff against a uniformly randomizing opponent (Harsanyi and Selten, 1988).

These kinds of games, which can be generalized to include more players and actions (Van Huyck, et al., 1990; Weber, et al., 2001; Brandts and Cooper, 2006), represent useful models of varied economic activity, such as investment or production under complementarities (Bryant, 1983; Hirschleifer, 1983; Knez and Camerer, 1994). But, despite the intuitive appeal of payoff-dominance and efficiency as an equilibrium-selection criterion, considerable laboratory evidence indicates that tacit efficient coordination is often difficult. For example, in the game in Table 1, the secure and inefficient (1,1) outcome regularly obtains when players play repeatedly and are re-matched across rounds (Cooper et al., 1992). Similarly, large groups in variants of the game with more players and actions rarely coordinate on the efficient equilibrium tacitly (Van Huyck, et al., 1990 & 1991). Identifying mechanisms that aid coordination on efficient equilibria is therefore potentially important for understanding how to obtain efficiency in analogous real-world coordination problems.

One natural way to facilitate efficient coordination might be to allow pre-play communication among players. Indeed, several experimental studies demonstrate that requiring all players to send non-binding pre-play ("cheap talk") messages, which correspond to possible actions in the game, can increase coordination on the payoff-dominant equilibrium (Cooper et al., 1992; Blume and Ortmann, 2007).[1] A stylized fact observed in these experiments can be described as follows: when both players in the game in Table 1 must send a message of either "1" or "2" prior to playing the game, both players send message "2" and coordinate on the (2,2) equilibrium. The same result regularly obtains when there are more players and actions, as in a minimum-effort, or "weak-link," coordination game (Blume and Ortmann, 2007).

Because the introduction of real-world features, such as pre-play communication, often yields efficient coordination in laboratory experiments on coordination games, one might argue that the frequency of coordination failure outside the laboratory is likely to be mitigated by the presence of such factors (Devetag & Ortmann, 2007). Since pre-play messages dramatically reduce coordination failure, the availability of communication in most real-world contexts implies that coordination problems analogous to the one in Table 1 are likely to be easily efficiently resolved.

However, in considering the extent to which communication solves coordination problems, one must remember that the amount of communication used in previous experiments to obtain high rates of efficiency in these games is perhaps unrealistic outside the laboratory. In the communication experiments above, efficiency typically obtains from i) *all* players sending messages indicating the intention to play the strategy corresponding to the efficient equilibrium, ii) all players observing messages from *all* other players, iii) this kind of intensive communication taking place *every* time the game is played, and iv) common knowledge of this communication structure. Under such stringent conditions, it is perhaps unsurprising that communication is highly effective. But such extreme forms of communication are unlikely to be found in many situations outside the laboratory.

When communication does not satisfy the above conditions, it is often much less effective at producing coordination on the efficient equilibrium. For example, Cooper et al. (1992) conduct a treatment in which only one player sends a pre-play message and find significantly lower levels of efficient coordination than when both players send messages. Similarly, Weber et al. (2001) find that communication from one player in a multi-player variant

[1] For theoretical analyses of the role of communication in these kinds of coordination games, see, for example, Farrell (1988), Farrell and Rabin (1996) and Ellingsen and Östling (2010). See also, Crawford and Sobel (1982) and Crawford and Haller (1990) for related discussions.

of the stag hunt game has little effect at improving efficiency.[2] Using a similar game, Chaudhuri, et al., (2009) find that inter-generational communication only yields efficiency under the extreme communication and information conditions described above.

The starting point for our research is this observation: The universal communication shown to be highly effective for obtaining efficient coordination in previous experiments is likely to be rare outside the laboratory. Our research explores the effectiveness of an alternative communication framework, which relaxes the requirement that players send pre-play messages and therefore makes the laboratory consistent with many non-laboratory environments in which communication is voluntary, irregular, and costly. By introducing communication costs, our experiment also creates situations in which the use of pre-play messages is inefficient, as in many naturally occurring contexts.

More precisely, we depart from the above seminal experiments by Cooper et al. (1992) in two important ways. First, rather than exogenously imposing a communication structure on a group by deciding who sends messages and requiring those people to do so in every period, we make the choice of whether to send a message endogenous, by allowing players to decide whether they want to send a message in each period.[3] Second, we require those players who choose to send messages to incur costs to do so. That is, we make communication costly to reflect the fact that real-world communication often imposes costs – e.g., explicit communication costs or an opportunity cost of time – on those who use it.

Importantly, the kind of communication we introduce in our experiments changes the efficiency properties of equilibrium outcomes. Since messages are costly and players are not required to send messages, efficiency no longer obtains when explicit communication is used to obtain the (2,2) outcome in the game in Table 1. Such an outcome is Pareto-dominated by obtaining the same (2,2) game outcome without the use of explicit communication, i.e., tacitly. This applies to many non-laboratory environments, where costs associated with using communication mean that its use necessarily diminishes efficiency. Of course, evidence from prior experiments, discussed above, suggests that tacit coordination is rare and difficult in such

[2] For theoretical analysis of the effectiveness of unilateral vs. multilateral communication, see Ellingsen and Östling (2010). Also, 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).

[3] Our paper is related to recent theoretical research that explores endogenous information acquisition in coordination games, as when players must decide which, of many possible, coordinating signals to which to attend (Dewan and Myatt, 2008; Myatt and Wallace, forthcoming),

games. Perhaps, then, truly efficient (message-free) coordination is unobtainable, and the best one can hope for is for players to coordinate their actions in the game efficiently, but only while incurring the inefficient costs associated with using pre-play messages.

To preview our findings, in light of the previous experimental evidence our main result is somewhat surprising. Despite the fact that tacit communication is rare in previous experiments, and in one of our baseline conditions in which subjects are not allowed to communicate, we find that it occurs regularly when subjects choose to forgo costly communication. That is, when we make the choice to send a message both endogenous and costly, we find that subjects generally opt not to send messages, but that they subsequently coordinate their actions efficiently with high frequency. The difference between treatments is evident from the first time subjects play the game.

Importantly, however, the above efficient coordination with forgone message use only occurs when message costs are low enough that sending a message is not a dominated strategy. That is, when message costs are low enough that subjects might reasonably use explicit pre-play communication to facilitate coordination, tacit coordination on the efficient equilibrium in the game occurs without subjects actually having to use messages. However, when message costs are high enough that no one should ever employ pre-play communication, then not using it does not help obtain efficient coordination in the game. Thus, the absence of messages means different things based on how they could have been used or whether they were possible. Intuitively, therefore, one can summarize our main finding as follows: Players are reassured in the coordination game in Table 1, absent any pre-play messages, simply by knowing that their opponent could have (reasonably) used pre-play messages to facilitate coordination.

Our results are consistent with a theoretical analysis based on forward-induction, in which players infer from the absence of "reasonably costly" messages that the other player intends to play the efficient action. Thus, knowing that the other player could have communicated, if she felt it necessary, is sufficient to provide the reassurance necessary to yield efficient coordination. Our results are important as they indicate that, in real-world settings where pre-play messages are costly, one may observe significant efficient coordination without reliance on such messages.[4] This constitutes a significant departure from prior research, which suggests that efficient coordination is difficult without explicit pre-play communication.

The rest of our paper is organized as follows. Section II provides a theoretical analysis that yields predictions for our experiment. Sections III and IV present the experimental design and results, respectively. Section V concludes.

II. Theoretical Analysis and Hypotheses

Our analyses and experiment modify the game in Table 1 in two ways. First, we introduce an initial stage in which both players simultaneously decide whether to send no message, or to send a message of "1" or "2" to the other player. Both players then observe any message sent by the other player, before selecting an action in the second-stage coordination game. Second, we introduce a cost of sending a message, $c \geq 0$, which is not incurred when a player chooses to send no message. We refer to the special case when $c = 0$ as costless messages. The primary focus of our analysis and experiment deals with situations in which $c \in (0,200)$, meaning that pre-play communication is costly but can be supported as part of an equilibrium strategy (i.e., sending a message is not dominated). We refer to such a situation as one involving "reasonable" communication costs. We also consider the case where $c > 200$, meaning that sending a message is possible but dominated – i.e., "unreasonable" message costs. Whether message costs are above or below 200 significantly affects both our theoretical analysis and the experimental results. We begin by considering the case of reasonable message costs ($c \in (0,200)$), which is the focus of our study, and return later to the cases with costless communication ($c = 0$) and unreasonable message costs ($c > 200$).

In the game modified by voluntary communication, each player has 24 possible pure strategies, involving three possible message-stage choices (no message, "1", "2") and eight

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[4] Two recent experimental papers explore different kinds of 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 higher (more efficient) strategies, but this does not translate into better coordination because of the infrequency with which subjects use smiles and the small effect of messages. A treatment with costly smiles yields significantly reduced use of these messages (less than 1 percent of cases result in both players smiling), though the ambiguous benefit of costless smiles make it difficult to predict what should happen when costs are introduced. Fehr (2011) finds that players infrequently vote to impose a costly communication regime on all players, prior to merging two three-person groups playing a coordination game, resulting in coordination failure. This research suggests that people fail to properly anticipate the benefit of costly pre-play messages. This contrasts with our main prediction (from the next section), which suggests that players will fail to send messages because they are *unnecessary* when costly, at least in the two-player game we study here.

possible actions in the second-stage game (a choice of 1 or 2 for each possible message-stage choice by the opponent). We restrict our attention to the most intuitively plausible and interesting actions and outcomes. Call an equilibrium *semantically consistent* if messages are used in agreement with their semantic meaning. We restrict attention to the three equilibrium outcomes that are supported by pure, symmetric, and semantically consistent equilibria.[5] When $c \in (0,200)$, there are three such outcomes: i) players send no message and take action 1, ii) players send message "2" and take action 2, and iii) players send no message and take action 2. Only the third case is efficient, as it yields both players the highest payoff from the game without incurring message costs.

Given our focus on semantically consistent equilibria, it makes sense to completely eliminate message "1" from the formal analysis of the game. To see this, observe that the only reason for players who maximize material payoffs to send a costly message is to induce action 2. Using message "1" with the intent to induce action 2 would violate our semantic consistency condition. Finally, once the use of message "1" with the intent to induce action 2 has been removed from consideration, there is no reason for materially motivated players to send message "1" at all.[6]

With this in mind we focus our analysis on a game in which only the options of not sending a message or of sending message "2" are available. This results in the game with 8 pure strategies described in Table 2. 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.

Note that, like the two pure-strategy equilibria in the original game without communication (Table 1), in the game modified by reasonable communication costs ($c \in (0,200)$) the three semantically consistent, symmetric, pure-strategy equilibrium outcomes can

[5] Pure-strategy equilibria most clearly exemplify the possible differences in message use and in our game the exclusion of mixed equilibria does not move the Pareto frontier. Symmetry appears sensible in an environment with random anonymous matching where players cannot acquire role distinctions. Semantic consistency is focal and given that the two messages in our game are equally costly is not restrictive in terms of payoffs.

[6] One plausible reason for sending message "1" might be other-regarding preferences. A player who intends to take action 1 is materially unaffected by whether the other player takes action 2, but the other player would suffer a payoff loss in that instance. Thus, a player who intends to take action 1 and has altruistic concerns for the other player may want to let the other player know about his intentions by sending message "1." This suggests that players sending message "1" will tend to play action 1 in the game.

also be ranked in terms of efficiency. Coordination on (1,1) without messages (supported by actions *N21* and *N11*) is the least efficient equilibrium outcome, yielding both players a payoff of 800. Using message "2" to coordinate on (2,2) (supported by actions *M22* and *M21*), which is efficient when $c = 0$ as in Cooper et al.'s experiment with costless communication, is now also inefficient as it yields both players a payoff of 1000-*c*. Efficiency obtains only under tacit coordination, when players do not send messages and coordinate on (2,2) (supported by actions *N22* and *N12*), yielding payoffs of 1000.

To understand our selection among these three symmetric and semantically consistent pure-strategy equilibrium outcomes, it may be helpful to recount a well-known forward-induction narrative. Forward induction expresses the idea that players try to use the history of the game to infer future play. Specifically, players try to rationalize unexpected moves of other players as best as they can.[7]

For concreteness assume that the game is played between Ann and Bob. Ann knows that Bob can guarantee a payoff of 800 by selecting "no message" and then taking action 1. With this in mind how should she interpret a reasonably costly message "2" from Bob? She might reason that since sending a costly message and then taking action 1 is (strictly) dominated by selecting "no message" and taking action 1, Bob must expect a higher payoff in the ensuing post-communication subgame than 800. The only way for Bob to achieve a payoff greater than 800, after sending a message, is to take action 2 to obtain a payoff of 1000-c. Hence, Bob's intention must be to take action 2 in the subgame and therefore Ann's appropriate response to a reasonably costly message "2" is to take action 2 herself.

Taking this one step further, if both Ann and Bob accept this reasoning, then they believe that by sending message "2" Bob can guarantee a payoff of 1000-c. Hence, if Ann receives "no message" she should believe that Bob expects a payoff of at least 1000-c in the post-communication subgame. The only way to achieve such a payoff, when $c \in (0,200)$, is for both players to choose action 2. Thus, if Ann receives "no message" she should expect Bob to take

[7] The somewhat elusive forward-induction idea likely originated with Elon Kohlberg (according to Battigalli and Siniscalchi (2002)) and one of the earliest references is Kohlberg and Mertens (1986). Multiple solution concepts (strategic stability, iterative deletion of weakly dominated strategies, rationalizability, etc.) capture versions of forward-induction reasoning. Prior research using the kinds of coordination games we study here similarly demonstrates that history can affect equilibrium selection; specifically, having players pay to play the coordination game facilitates efficiency (Van Huyck, et al., 1993; Cachon & Camerer, 1996; Crawford & Broseta, 1998). However, these results are not entirely consistent with forward induction, nor do they clearly generate predictions for our experiment.

action 2 and should therefore take action 2 herself. Similarly, reversing the roles of Ann and Bob, if Bob receives no message, he should take action 2. On the basis of this argument one would predict that, when players can choose whether to send costly messages, both Ann and Bob refrain from sending messages and then take action 2.

Ben-Porath and Dekel (1992) demonstrate for a class of games where only one player can send a message (or, can "burn money") that the above type of forward-induction narrative can be captured by iterative deletion of weakly dominated strategies: At the unique equilibrium outcome that remains after iterative deletion of weakly dominated strategies no money is burned and the player who can send messages achieves his favorite equilibrium outcome.[8]

With two-sided communication, iterative deletion of weakly dominated strategies fails to capture the forward-induction logic. However, forward induction can be supported using the strategic stability concept of Kohlberg and Mertens (1986). Our analysis in Appendix A demonstrates how this approach uniquely selects, for the modified game in Table 2 and for reasonable communication costs ($c \in (0,200)$), the efficient equilibrium in which players send no messages and select action 2. Further support for this prediction comes from the fact that this predicted outcome in our game is the unique outcome that is supported by equilibria belonging to a minimal *curb* (closed under rational behavior) set. Curb sets (Basu and Weibull, 1991) are sets of strategies that are closed under inclusion of best replies and minimal curb sets frequently capture the forward-induction property.[9]

Based on these observations, ***we predict that in our experiment, 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 1).* Given that Cooper et al. (1992) and others found coordination difficult to achieve without pre-play messages, this theoretical hypothesis is of special interest.

The curb concept can also be used to address equilibrium selection when messages are costless ($c = 0$). Blume (1998) shows that, with multi-sided pre-play communication, if the underlying game has a unique efficient action profile then under a mild behavioral assumption (that agreement on an equilibrium action profile confers an infinitesimal payoff boost to that

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[8] Huck and Mueller (2005) find some, although not overwhelming, support for the forward-induction prediction in a variant of the battle of the sexes where one of the players is given the opportunity to burn money before the game.

[9] Hurkens (1996) uses the minimal curb notion to obtain a very powerful result for environments in which a subset of players can send costly messages (burn money) before a game is played: All players who can burn money obtain their favorite equilibrium outcome and no money is burned in equilibrium.

profile) every strategy profile in the unique minimal curb retract is an efficient equilibrium. Based on this, ***we predict that in our experiment, 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 2).* That is, we expect to replicate the findings of Cooper et al. (1992) in this environment.

We next consider the case with unreasonably costly messages ($c > 200$). Here, the above forward induction intuition and analysis fail because 1000-c < 800, which means that sending a message, regardless of the outcome in the second-stage subgame, is strictly dominated by not sending a message and selecting action 1. That is, all of the "M" strategies in Table 2 are strictly dominated. Thus, to return to our earlier example, the absence of a message from Bob tells Ann nothing about what Bob intends to do, as he would never send a message. The elimination of all strategies that employ messages reduces the game to the game in Table 1. Prior research, e.g., Cooper, et al. (1992), indicates that behavior in this game will converge to the inefficient (1,1) equilibrium. Therefore, ***we predict that in our experiment, with unreasonably costly messages*** ($c > 200$)), ***the modal behavior will be for players not to send messages and to take action 1*** *(Hypothesis 3)*.

We make the same prediction for the treatment in which messages are not possible, and message costs are therefore implicitly infinite. That is, ***we predict that in our experiment, with no messages***, ***the modal behavior will be for players to take action 1*** *(Hypothesis 4)*. As with Hypothesis 2, this essentially predicts a replication of Cooper, et al. (1992).

It is also worth noting here that the minimal curb requirement combined with Blume's (1998) behavioral assumption, which we use above to provide a prediction for the treatment with costless communication, also yields a prediction for the treatment with reasonably costly communication. In both cases the unique minimal curb set supports only efficient outcomes, which is consistent with our above predictions: With reasonably costly messages no message is sent and action 2 is taken (Hypothesis 1); with costless messages, message 2 is sent and action 2 is taken (Hypothesis 2). Without messages or with messages that are so costly as to be dominated actions, the behavioral assumption is of no consequence, and the minimal curb condition does not discriminate between the two strict equilibria of the underlying game. It is worth noting that these predictions are obtained without invoking either of our earlier restrictions to pure strategies or to equilibrium outcomes that are supported by pure strategies. The semantic consistency condition also disappears, but Blume's behavioral assumption makes reference to the literal meaning of messages and thus is in a similar spirit.[10]

Our predictions are in terms of modal behavior and do not explicitly account for noise that will likely exist in the data. A solution concept that explicitly incorporates noise is Quantal Response Equilibrium (McKelvey and Palfrey, 1995). In a Quantal Response Equilibrium (QRE), players choose strategies probabilistically, assigning higher probability to strategies with higher payoffs. For comparison purposes we examined the limit behavior of QRE as we trace equilibria continuously from complete noise to no noise.[11] We conduct the analysis for the three levels of costs, $c = 10$, and $c = 100$ and $c = 300$, that we introduce in the experiment. We find that in the 8x8 game in Table 2 (limit) QRE predicts that action 1 is taken with no message, regardless of message costs. This contrasts with the forward-induction logic that guides our predictions and which discriminates between treatments with different message costs.[12]

With these hypotheses in mind, we proceed to our experimental test.

III. Experimental Design

The experiment is modeled after Cooper et al. (1992), in which subjects played the game in Table 1 both with and without communication.[13] 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 Carnegie Mellon University, the University of Pittsburgh and the surrounding community.

[10] Being able to dispense with the symmetry and pure-strategy outcome restrictions is reassuring because, while they helped us highlight some of the central strategic considerations players face in our game, they are not entirely innocuous. For example, permitting outcomes that are supported only by mixed equilibria changes the leverage that strategic stability has in the analysis. Specifically, the game in Table 2 has a singleton strategically stable equilibrium in which both players mix over M22 and N21. In this equilibrium each player faces a tradeoff between the cost of guaranteeing efficient continuation play and the risk of both players failing to send a message.

[11] We do so using the GAMBIT software developed by McKelvey, McLennan and Turocy (2007).

[12] We also considered another approach to modeling bounded rationality in games (Level-*k*), which prior analysis finds can account for the findings of many experiments using communication in coordination games (Ellingsen and Ostling, 2010). We find that the model does not adequately explain our results. Particularly, it does not account for (2,2) play with no messages. The analysis is available from the authors, on request.

[13] Other than the treatment differences, our design choices generally follow those of Cooper, et al., with the exception that we simplified the procedure where possible and also 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 (in random order), we used random matching. And finally, instead of a payoff procedure that involved a lottery, we converted all earnings in ECU directly into U.S. dollars (with an exchange rate that kept the numerical payoffs in the stage game consistent with Cooper et al.).

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.[14] 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.

Experimental Conditions

The five conditions are summarized in Table 3, which also presents the relevant cost parameter, *c*, for each condition. We also include our theoretical predictions.

We conducted a no communication baseline (*No Messages*) in which subjects played the game repeatedly with re-matching after every period. In this treatment, participants played the one-shot stag hunt game in Table 1 for forty periods. The payoffs in Table 1 corresponded to "Experimental Currency Units" (ECU), and were converted to dollars at the end of the experiment at the known exchange rate of $1 per 2500 ECU. 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 (own choice, opponent's choice and resulting outcome), 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, consistent with our analysis in Section II. 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 either "no message", "1", or "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 this treatment differs slightly from Cooper et al.'s two-way communication treatment, in which messages were costless but subjects were required to send messages, 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

[14] The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007). Instructions are available in Appendix B.

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 analysis predicts different behavior for the two kinds of message costs, as presented in Table 3.

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 3).

We find that message costs strongly affect message use. Under Costless Messages, message "2" was sent 89.3 percent of the time. However, with 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 $c = 300$.[15] Thus, the data generally support our predictions concerning message use – message "2" is used very frequently with Costless Messages, but rarely in all

[15] 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. These observations generally support the assumption of semantic consistency and elimination of message "1" in the analysis.

conditions with Costly Messages.

Table 4 reports probit regressions, with subject random effects, using the choice to send message "2" as the dependent variable. The regressions use only data from the four treatments in which messages were possible. As model 1 reveals, the frequency of message use is significantly lower in all Costly Message conditions, relative to the condition with Costless Messages.[16] Thus, message costs – even very small ones as in RC-10 – significantly decrease message use.[17]

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 each 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 in that condition. When messages were Costless, a large majority of subjects sent message "2" in every period.[18] However, in the three Costly message conditions, the modal behavior was to send no messages at all.

While we find, as we 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 conditions. The data reject this interpretation. As model 2 in Table 4 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 frequency of message "2" use in any period is 34.2 percent in

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[16] 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 ($z = 2.36$, $p < 0.02$).

[17] 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.

[18] Three subjects in Costless Messages rarely or never sent message "2" even though doing so was costless. One of these subjects 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 as mentioned in footnote 6).

RC-10, 17.1 percent in RC-100, and 12 percent in UC-300 – and it is never lower than 83.3 percent in any period of the Costless Messages condition.

The message use by subjects in the experiment therefore strongly confirms our predictions in Table 3. 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 Hung Game

We now consider the second part of the predictions in Table 3, 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. 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.[19] With Costless Messages, we 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. Therefore, we find support for Hypotheses 2 and 4.

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 messages. 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 1). The availability of optional, and

[19] There is some heterogeneity across sessions, particularly in the No Messages condition (see Figure 6). 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 13).

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 3). 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. 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 5 reports random-effects probit regressions 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 ($\chi^2(2) = 4.32$, $p = 0.12$).

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 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 5 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 ($\chi^2(3) = 11.64$, $p < 0.01$), and do not differ statistically from each other ($\chi^2(2) = 1.98$, $p = 0.37$).

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 4), 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. The forward-induction argument on which our main prediction is based is supported by the fact that, message costs become unreasonable ($c > 200$), subjects also send few messages but modal behavior changes dramatically toward action 1. All of this is supported both when considering 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 choice behavior. To provide a stronger test, we can also consider these two aspects of a player's strategy jointly. At the root of our main prediction (Hypothesis 1) is that subjects in the Reasonably Costly conditions 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 frequency of action choices 2 (dark shading) and 1 (light shading) conditional on a message of "2" being sent or received in each condition.[20] 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 players 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 (top, right) or sent a message but did not receive one (bottom, left), we find interesting differences between the communication treatments. With Costless Messages, such

[20] In the few instances in which subjects sent a message of "1" they and their opponents usually subsequently chose action 1. This is consistent with subjects who decide to play action 1 in the game and exhibit other-regarding preferences towards their opponent (see footnote 6).

communication outcomes resulted in fewer than half of subjects playing action 2 subsequently.[21] In the conditions with Reasonably Costly messages (RC-10 and RC-100), however, the proportion of action 2 choices is much higher in both panels, and is close to one. With Unreasonably Costly messages, subjects who send such messages (2, none) are highly likely to select action 2, but receiving such a message without having sent one (none, 2) yields fewer action 2 choices than with Reasonably Costly messages.

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%).[22] Thus, as we hypothesized, the absence of messages results in different action responses based on 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 5 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 statistically insignificant, while the coefficient for Received Message "2," which applies to this condition, becomes positive and statistically significant. This shows that simply being in the Costless Message condition does not increase 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. That is, action 2 choices increase significantly from simply being in these conditions, regardless of whether a message of "2" is received, as we hypothesized.[23]

[21] 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 18). The Costless Messages data in the (2, none) panel is composed almost entirely of *responses* to these subjects by their opponents.

[22] 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.

[23] 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.

Of course, 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 model 5 we examine behavior in the first period alone, looking at the frequency of action 2 choices *only* in cases where no messages were used by either player.[24] 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 must play the stag hunt game without either receiving a message from or sending one to an opponent behave differently depending on what type of communication was possible, consistently 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 cases are quite high. The graphs also reveal little change in behavior over time.

D. Outcomes and Earnings

We next examine how the above action choices influence the outcomes and subject earnings achieved in the five conditions. The upper panel of Figure 5 presents the frequency over all forty periods of the three possible game outcomes – (2,2), (1,1), or miscoordination, in which action choices differ – by condition; the lower panel does so for the last 10 periods. Consistent with Hypotheses 1 and 2 and the above analysis of actions, the modal outcome under Costless or Reasonably Costly messages is (2,2). Consistent with Hypotheses 3 and 4, the modal outcome under No Messages or Unreasonably Costly messages is (1,1).

Table 6 presents mean subject earnings per period by condition, including any costs incurred from sending messages in the three conditions with costly communication. Not surprisingly, the mean payoff is low under No Messages or Unreasonably Costly messages,

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[24] 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 message 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.

which Figure 5 shows also yield the highest frequencies of (1,1) and miscoordination outcomes. While Costless Messages yielded higher mean payoffs than either of the Reasonably Costly message conditions over the entire experiment, these differences decreased over time. In fact, mean payoffs over the last ten periods are very similar under RC-100 and under Costless Messages.[25]

Table 7 presents OLS regressions, using a subject's mean payoff, including message costs, across all periods as the unit of observation and including session random effects. The first model simply shows the treatment differences. Mean payoffs are significantly higher under Costless or Reasonably Costly messages, relative to the No Messages baseline. Mean payoffs are slightly lower under Unreasonably Costly messages, but this difference is not statistically significant.

Model 2 considers how a subject's message use affects earnings. The variable "Frequency of Message Use" is the proportion of periods in which a subject sent message "2" – i.e., 0 for a subject who never sent messages and 1 for a subject who sent message "2" in every period (this statistic is analogous to the one reported in Figure 1). The first coefficient for this variable measures the effect of message use under Costless Messages, while the remaining interaction variables measure the marginal effect for the corresponding condition. As model 2 reveals, subjects in the Costless Message condition earned more than those in the (omitted) No Messages condition only if they regularly sent messages. However, in the two conditions with Reasonably Costly messages, even subjects who never sent messages earned more, and there was little additional benefit from sending messages. Not surprisingly, subjects earned considerably less if they sent Unreasonably Costly messages.

E. Heterogeneity Across Sessions

Most of our prior analysis aggregates behavior across sessions, which may hide between-session heterogeneity. We present in Figure 6 results from the individual sessions for each

[25] As illustrated by the lower panel of Figure 5, the relatively low profits in RC-10 relative to RC-100 in the last ten periods, despite the similarity in action choices (see
Table 4) are due to the higher frequency of miscoordination (17.4% in RC-10 vs. 4.0% in RC-100: $z = 2.125$, $p < 0.05$, M-W with average earnings in a session as the unit of analysis). Only one of the RC-10 sessions had less than 10% miscoordination over the last ten periods while only one of the RC-100 sessions had more than 10% miscoordination over the last ten periods. While this observation is entirely post-hoc, we speculate that the size of the costs may affect the degree to which common understanding arises regarding whether the absence of a message implies action 1 or 2.

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 3):[26] low message frequency and high action 2 frequency under Reasonably Costly messages (H1), high message frequency and high action 2 frequency under Costless Messages (H2), low message frequency and low action 2 frequency under Unreasonably Costly (H3) or No Messages (H4). 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 19). 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). Meanwhile, no session with Unreasonably Costly messages obtained an action 2 frequency greater than 0.3. Thus, while there is some heterogeneity at the session level, the behavior in a large majority of sessions generally conforms to our predictions.

V. Conclusions

We present novel experimental results that address how economic agents resolve coordination problems and the role communication plays in obtaining efficient equilibrium selection. Prior research suggests that, where efficient coordination is difficult, explicit pre-play communication provides a natural solution. Thus, based on this research, one might expect to see people regularly communicating whenever coordination problems like the stag-hunt game arise. Our research presents a significant departure from such conventional wisdom.

We begin by recognizing that, in many real-world organizational and economic contexts, explicit communication is costly. Scheduling a meeting or holding a conference call require using resources, and agents often must decide whether they are willing to bear these costs.

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[26] To account for possible noise in the data, our hypotheses state 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.

Therefore, relying on messages to facilitate efficient coordination of actions creates inefficiency – it would be better to obtain the same outcome without costly explicit communication.

Our analysis and results show that, when communication costs are explicitly included as part of message use, people no longer use messages but nevertheless coordinate their actions efficiently in the second-stage game. That is, rather than requiring people faced with stag-hunt-like real-world coordination problems to regularly and extensively communicate to reassure one another about their intended actions – as prior experimental evidence suggests one should solve these kinds of coordination problems – our results indicate that it might be sufficient for people to know that the other party *could have communicated, if she thought it was necessary*. Our theoretical analysis supports this intuition, by appealing to the concept of forward induction.

The results of our experiment are conclusive in supporting our theoretical predictions. For reasonably costly messages – i.e., messages that one would be willing to send if they facilitated efficient coordination – players do not send such messages and yet appear to draw the necessary strategically reassuring inference from the fact that such messages could have been sent. As a consequence, we observe high frequencies of efficient coordination in the stag hunt game merely by players knowing that they could have used costly messages, without them actually having to use them. This suggests that explicit, and costly, communication may be far less necessary and prevalent in economic and organizational contexts resembling the stag hunt game than prior research suggests.

The results of a condition with unreasonably costly messages – which are so high that sending messages constitutes a dominated strategy – provide critical support for our predictions. In this condition, almost every factor is identical to that under reasonably costly messages (e.g., the presence of a message technology, the interface and instructions seen by subjects), except the message cost exceeds a threshold that our analysis shows is critical for the kind of forward-induction based inference that drives our main prediction. The fact that the results are clearly different between reasonably and unreasonably costly messages – subjects do not use messages in either case, but coordinate efficiently in the former but not in the latter – supports our argument that it is the inference subjects draw from unsent messages that is critical for our main result.

Our results also highlight the need to think critically about how important features of the real world can be incorporated into laboratory experiments, and how such inclusion can substantively alter the resulting inference one draws from an experiment. Based on prior findings one might assume that the best way to resolve difficult coordination problems is to encourage pre-play communication. But this conventional wisdom ignores the impact of communication costs, which make explicit communication inefficient. Our findings suggest that equally effective, and less costly, is to create the possibility of communication, highlight the fact that it is costly, and note that agents can always use it if they think it necessary.

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Table 1: Stag Hunt Game

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

Table 2: 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

Table 3: Experimental Conditions

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

Table 4: Random-effects Probit Regressions of Message "2" Use

Dependent variable: Subject sent message "2"	All periods		Period 1
	(1)	(2)	(3)
Reasonably Costly Messages (RC-10)	-4.384*** (0.404)	-4.410*** (0.440)	-1.372*** (0.313)
Reasonably Costly Messages (RC-100)	-5.165*** (0.400)	-5.218*** (0.438)	-2.035*** (0.329)
Unreasonably Costly Messages (UC-300)	-5.891*** (0.419)	-5.777*** (0.464)	-3.021*** (0.491)
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)	
Constant	2.771*** (0.323)	2.662*** (0.361)	0.967*** (0.272)
Observations	8800	8800	220
Number of subjects	220	220	220
Log Likelihood	-1884.94	-1880.18	-92.13

Both models include data from all conditions with messages and subject random effects
Standard errors in parentheses; * - p < 0.1; ** - p < 0.05; *** - p < 0.01

Table 5: Probit Regressions of Action Choice 2 in Stag-Hunt Subgame

Dependent variable: Subject chose action 2	All periods (1)	(2)	(3)	Period 1 (4)	Period 1 & no messages (5)
Costless Messages	2.346*** (0.390)	2.115*** (0.450)	0.746 (0.453)	1.198*** (0.387)	
Reasonably Costly Messages (RC-10)	2.132*** (0.328)	1.261*** (0.368)	1.997*** (0.367)	0.708** (0.284)	0.590* (0.345)
Reasonably Costly Messages (RC-100)	1.735*** (0.327)	0.649* (0.366)	1.602*** (0.320)	0.758*** (0.286)	0.664** (0.310)
Unreasonably Costly Messages (UC-300)	-0.353 (0.341)	-0.003 (0.383)	-0.480 (0.381)	0.067 (0.290)	0.136 (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 (0.272)	0.456 (0.308)	-0.435 (0.304)	0.084 (0.229)	0.084 (0.229)
Observations	10000	10000	10000	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; models 1 through 3 include subject random effects.
Standard errors in parentheses; * - $p < 0.1$; ** - $p < 0.05$; *** - $p < 0.01$

Table 6: Mean Payoff per Period (Including Message Costs)

	Costless Messages	Reasonably Costly (RC-10)	Reasonably Costly (RC-100)	Unreasonably Costly (UC-300)	No Messages
All 40 Periods	932	858	868	698	766
Last 10 Periods	923	875	926	758	813

Table 7: Determinants of Mean Payoffs (OLS)

Dependent variable: Mean profit for a subject	(1)	(2)
Costless Messages	166.7*** (56.51)	38.12 (58.38)
Reasonably Costly Messages (RC-10)	92.28* (47.76)	75.01* (40.99)
Reasonably Costly Messages (RC-100)	102.23** (47.76)	107.04*** (40.79)
Unreasonably Costly Messages (UC-300)	-67.37 (50.54)	-34.49 (43.05)
Frequency of Message Use		143.89*** (37.19)
Frequency of Message Use X RC-10		-73.20* (44.19)
Frequency of Message Use X RC-100		-186.53*** (52.69)
Frequency of Message Use X UC-300		-828.74*** (73.70)
Constant	765.67*** (39.96)	765.67*** (33.95)
Observations	250	250
Number of sessions	25	25
R^2	0.422	0.558

All models include data from all conditions and session random effects.
Standard errors in parentheses; * - p < 0.1; ** - p < 0.05; *** - p < 0.01

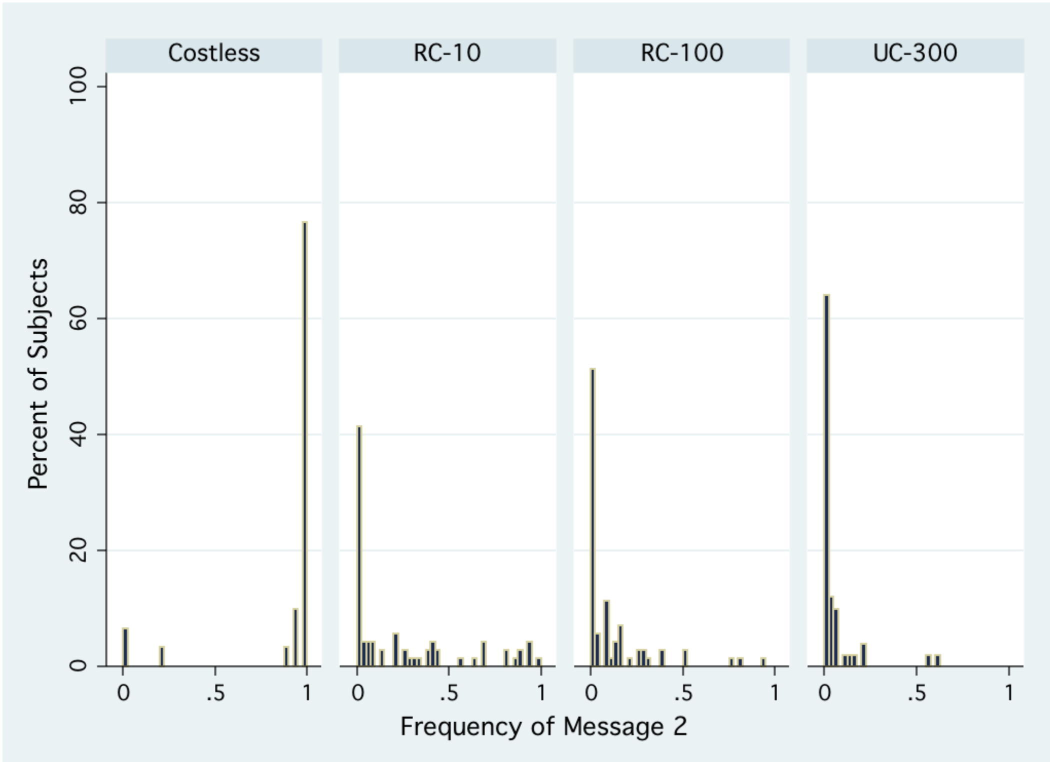

Figure 1: Distribution of Individual Frequency of Message Use by Condition

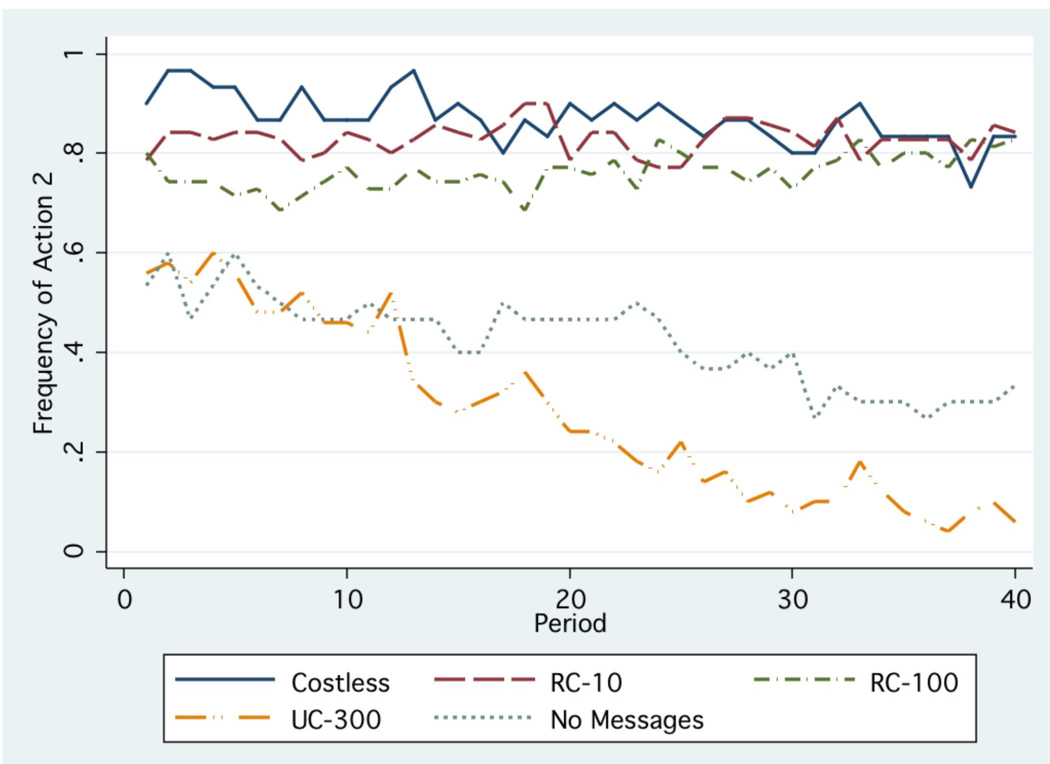

Figure 2: Action Choice over Time

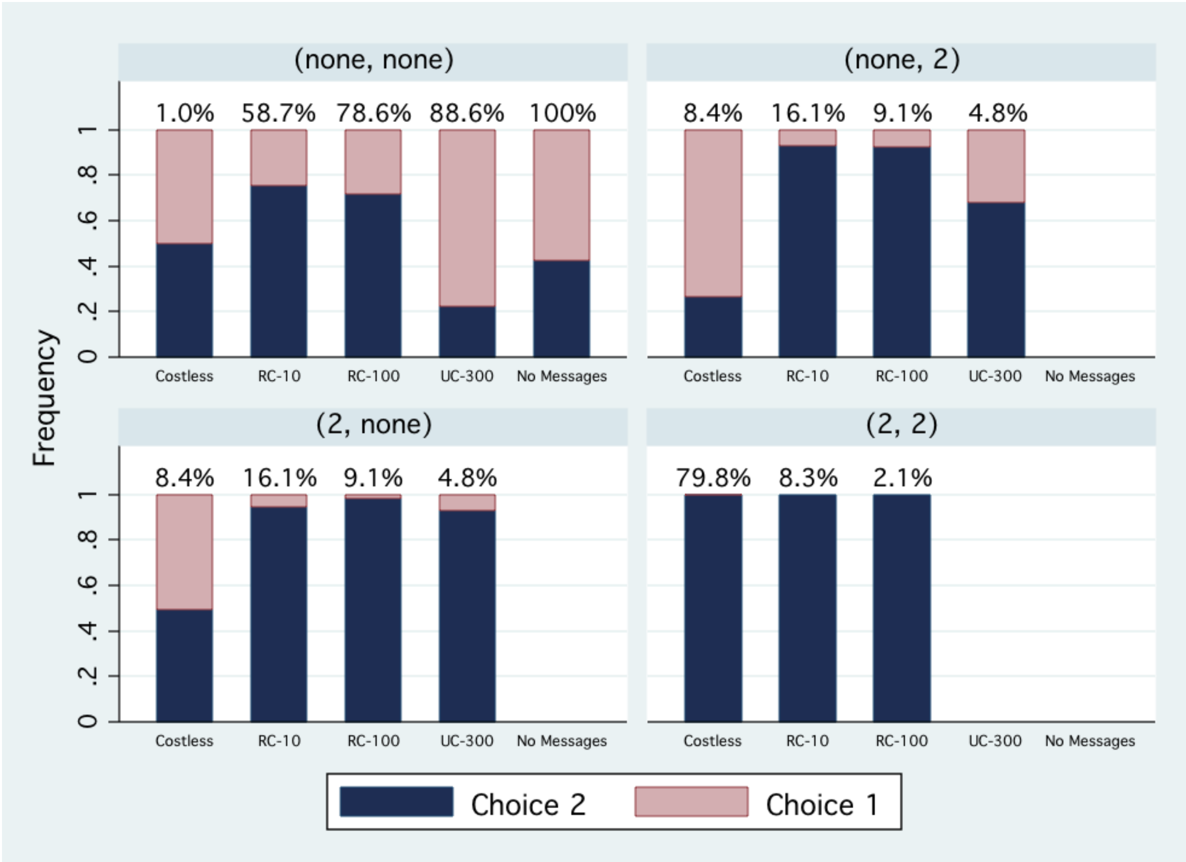

Figure 3: Choices Conditional on (Message Sent, Message Received)

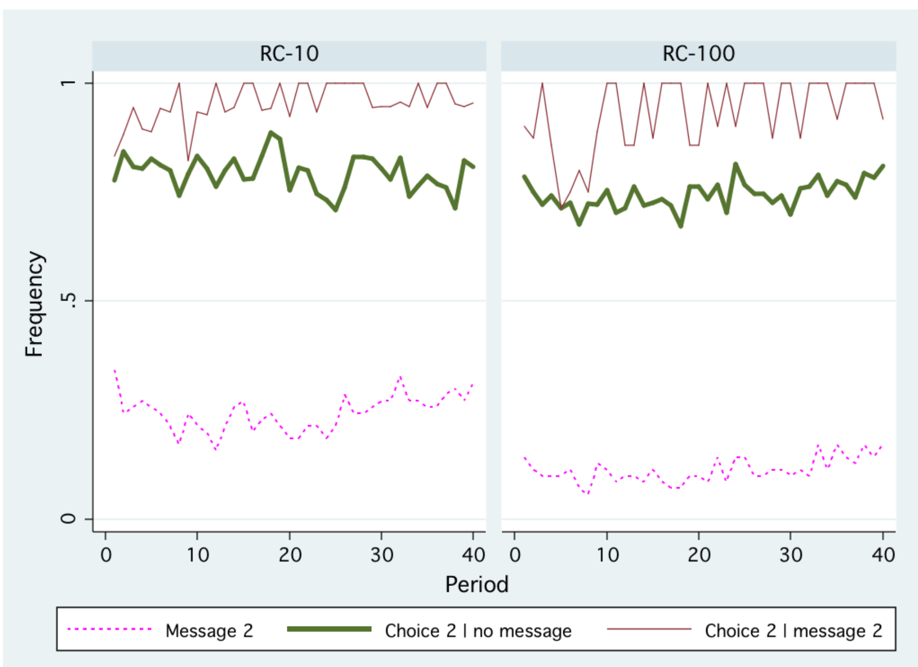

Figure 4: Choices Conditional on Message Received over Time

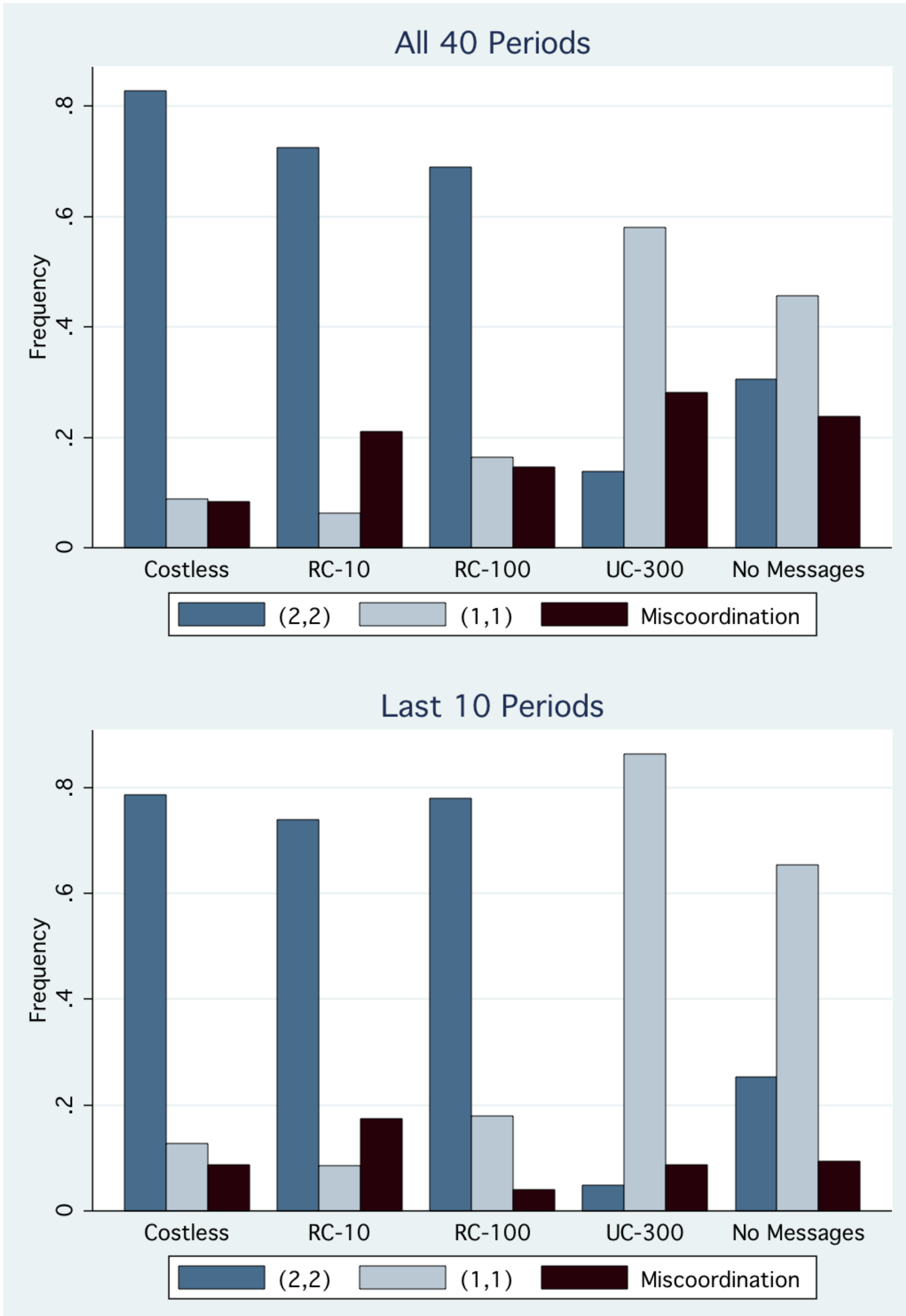

Figure 5: Game Outcomes by Treatment (All Periods and Last 10 Periods)

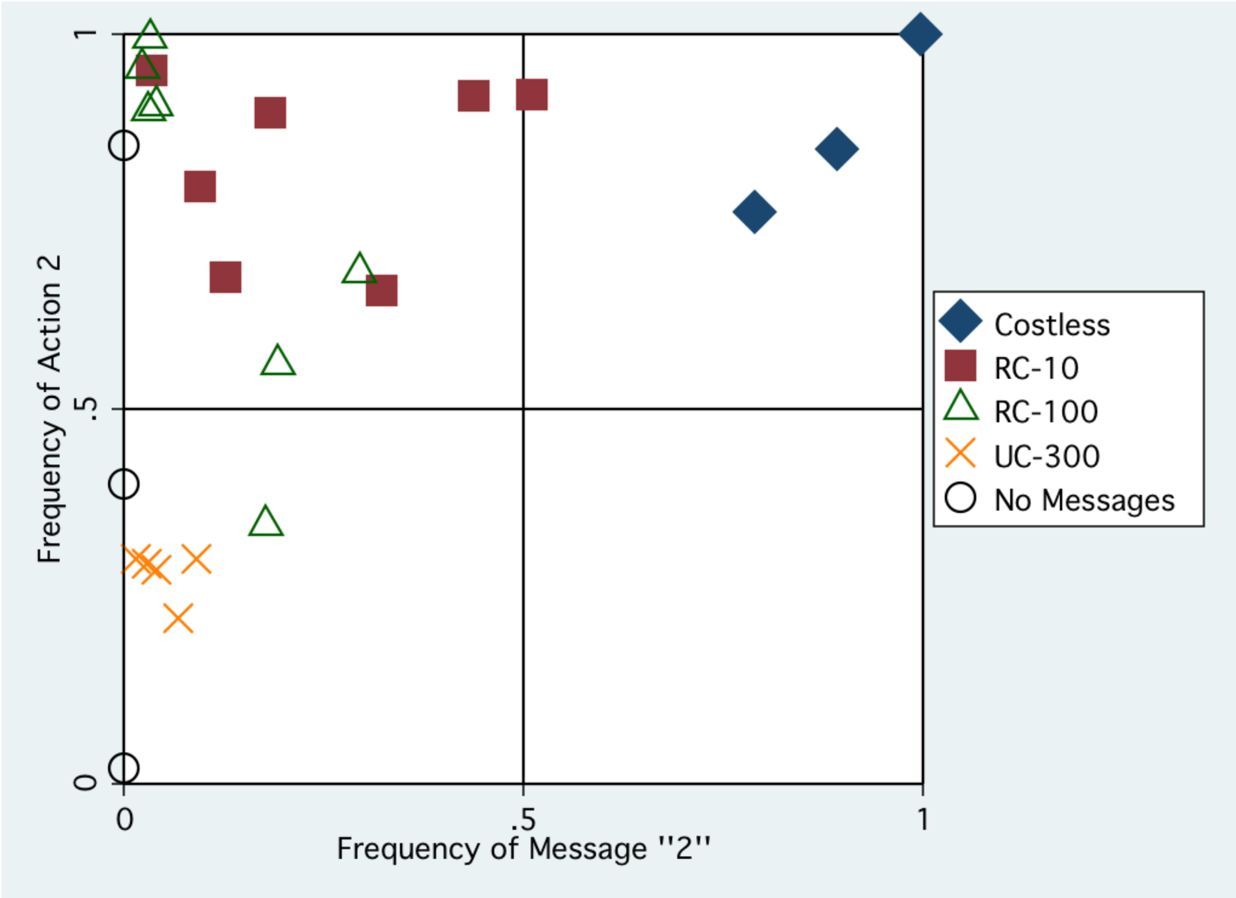

Figure 6: Message and Action Frequencies by Session

Appendix A: Analysis of Strategic Stability

We will make use of the following facts about stable sets of equilibria that were established by Kohlberg and Mertens (1986). First, there exists a stable set that is contained in a single closed connected component of the set of Nash equilibria. Second, stable sets satisfy *iterated dominance*, i.e. a stable set contains a stable set of any game obtained by deleting a dominated strategy; and third, stable sets satisfy the *never weak best reply property,* i.e. a stable set contains a stable set of any game that is obtained by deleting a strategy that is not a best reply against any equilibrium in the set.

We investigate which, if any, of the three equilibrium outcomes of interest is supported by a stable set of equilibria that belongs to a single closed connected component of the set of Nash equilibria. Consider the 8x8 reduced normal form of the game where players have a choice to either send no message or a message of "2" with cost $c \in (0,200)$ before playing the 2x2 base game. This game is described in Table 2 in the paper.

The outcome where players send message 2 and take action 2 is supported by the closed connected component of equilibria in which players play (possibly degenerate) mixtures of the strategies *M22* and *M21* and where the probability *p* with which *M22* is played satisfies $p \in [0, (1000 - c)/1000]$. Call this the 2-2 component. **The 2-2 component is not stable:** For both players, strategy *M11* is weakly dominated and strategies *M12*, *N12* and *N11* are not weak best replies against any strategy in the 2-2 component. In the game that remains when these strategies are deleted, the strategy *M21* is weakly dominated (by *M22*). But the game that remains once M21 is deleted does not have an equilibrium that belongs to the 2-2 component.

The outcome where players send no message and take action 1 is supported by the closed connected component of equilibria in which players play (possibly degenerate) mixtures of the strategies *N21* and *N11* and where the probability *q* with which *N21* is played satisfies $q \in [0, (800 + c)/1000]$. Call this the N-1 component. **The N-1 component is not stable**: For both players strategy *M11* is weakly dominated and strategies *M21*, *N22* and *N12* are not weak best replies against any strategy in the N-1 component. In the game that results once these strategies are eliminated, the strategy *N11* is weakly dominated (by *N21*). Once this strategy has been removed, the resulting game does not have a Nash equilibrium in the N-1 component.

The outcome where players send no message and take action 2 is supported by the closed connected component of equilibria in which players play arbitrary (possibly degenerate) mixtures of the strategies *N22* and *N12*. Call this the N-2 component. **The N-2 component is stable**: Regardless of how players mix over the strategies N22 and N12, any best reply to such a mixture is one of those two strategies or a mixture thereof. Therefore, for any perturbation of the game there is an equilibrium in which players put maximal weight on strategy N22, strategy N12 or a combination of the two.

In summary, among pure-strategy, symmetric and semantically consistent equilibrium outcomes in the game with reasonable communication costs ($c \in (0,200)$), only the one in which no message is sent and players take action 2 belongs to a stable connected component of equilibria.

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.

Continue

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.

Continue

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.

Continue

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.

Continue